

NOAA Center of Excellence for Great Lakes and Human Health OCEANS AND HUMAN HEALTH INITIATIVE

Progress Report and Statement of Work

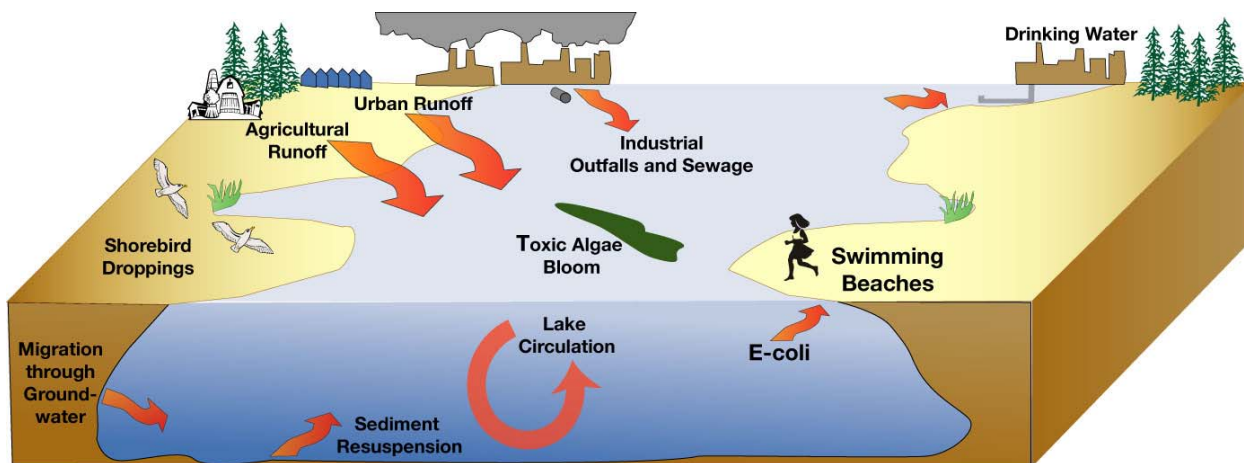
March 2006

FY 2005 Progress Report

Introduction and Background

As the largest freshwater source in the world, the Great Lakes are significant in the United States from an economic, ecological, societal, and geographical perspective. Housed between two countries, eight states and two provinces, the ecology and coastal environmental issues of the Lakes are as complex as the governance. The Great Lakes provide drinking water to 40 million US and Canadian citizens. In addition there are over 600 recreational beaches in the Basin and 56 billion gallons of Great Lakes water is used on a **daily** basis for municipal, agricultural, and industrial purposes. Nowhere are human health issues so interconnected to coastal regions than in the Great Lakes because of the high concentrations of humans, major cities and industries in the watershed. Sources of bacterial and nutrient contamination and their influences on drinking water quality, beach closings, and harmful algal blooms are tightly coupled to the processes and mechanisms that trigger loading events and hydrodynamic transport. Forecasting these threats to human health requires a multidisciplinary approach and will help in mitigating the economic, ecological, and societal impacts to users in the Great Lakes Basin.

Because water is an essential element for human survival, human health can be explicitly tied to water quality. Despite major advances in the last several decades, the water quality of the Great Lakes remains at risk due to population growth and stresses along the shore line, increased use, climate impacts and emerging contaminants (Figure 1). The Great Lakes are the only coastal waters in the Nation used as a source of drinking water. In 1993, a single drinking water incident in the Lakes caused over 100 deaths and 400,000 illnesses. Great Lakes beaches are used for swimming and other recreational activities and the rate of beach closures is increasing. According to the EPA's Great Lakes Indicator Data for beach closings, thirteen percent of reporting beaches were considered High Risk (closed at least 10% of the time) in 2004. Microbial contaminants continue to be one of the most frequently identified causes of impairment of waters in the Great Lakes Basin. The sources of these contaminants and fecal pollution include illicit waste connections to storm sewers or roadside ditches, septic systems, combined and sanitary sewer overflows, storm (rain) runoff, wild and domestic animal waste, as well as industrial and agriculture runoff.



Human health is profoundly affected by water quality in the Great Lakes. The US Great Lakes Policy Committee, which is comprised of all Federal, State and tribal agencies in the Great Lakes provided a vision for the Great Lakes in the Great Lakes Strategy 2002 that: (a) the Great Lakes Basin will be a healthy natural environment for wildlife and people (b) All Great Lakes beaches will be open for swimming (c) All Great Lakes fish will be safe to eat and (d) The Great Lakes will be protected as a safe source of drinking water. **To meet these goals, the major pathways from source, to loading, to transport for waterborne infectious microbial pathogens including exposure via both drinking water and recreational use, need to be identified.** Few data are available to improve the scientific understanding of the physical, chemical, and biological processes that control fate and transport of these microbial contaminants from point of release to point of exposure. The lack of integrated multi-disciplinary scientific investigation on waterborne microbial pathogens has prevented a sound scientific risk-based approach for predicting and preventing waterborne disease occurrences, particularly at a watershed level.

The NOAA Great Lakes Environmental Research Laboratory (GLERL) has a long history of employing a multidisciplinary research approach in the Great Lakes Basin. GLERL scientists approach research from a multidisciplinary, collaborative perspective, to build on knowledge and expertise to establish an ecological forecasting capability in the Great Lakes. The Center of Excellence for Great Lakes and Human Health (CEGLHH), a multidisciplinary research center that is housed in the National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory, in Ann Arbor, Michigan, extends GLERL's collaborative scientific approach. Established in June 2004, CEGLHH focuses on understanding the inter-relationships between the Great Lakes ecosystem, water quality, and human health. The overall purpose of the Center is to use a multidisciplinary approach to understand and forecast coastal-related human health impacts for natural resource and public policy decision-making, with the ultimate goal of reducing human health risks.

Although the Center is housed inside the Great Lakes Environmental Research Laboratory, the Center is comprised of multiple federal agencies, universities, and public health networks. There are twenty-four principal investigators, representing ten research entities. In addition the Center has partnerships with various universities, federal agencies, and a broad network of human health and municipal interests. CEGLHH is led by the NOAA Great Lakes

Environmental Research Laboratory, and the partners include Michigan State University, USEPA Chicago, US Geological Survey, Florida Institute of Oceanography, NOAA Beaufort Laboratory, NOAA NOS Silver Spring, USEPA Athens, Michigan Sea Grant Extension, University of Michigan, and the Great Lakes Human Health Network. CEGLHH uses a multidisciplinary approach to translate scientific information and research into materials to aid health officials, local governments, and communities in making sound environmental decisions. In addition CEGLHH works to assess user needs by collaborating with stakeholder groups.

The focus of the Center is on human health effects in the Great Lakes, related to three research priority areas: beach closures/health, drinking water quality, and harmful algal blooms. The understanding of ecosystem processes, particularly hydrodynamics and the influence of abiotic factors on the fate, transport of sources and loadings of bacteria and microbial contaminants will ultimately lead to sound environmental decision-making and reduce human health risks. There are many processes and events that can influence sources, transport, and loading of bacteria and nutrients to the lakes, such as land-use and meteorological processes. Defining and forecasting these relationships will be the primary research focus of the Center. Our research is concentrated on providing forecasts of water quality that can be used directly to reduce risks to human health associated recreational exposure and human consumption of Great Lakes water. Effective management of coastal ecosystems requires timely and continuing predictions of ecosystem change.

Ecosystem forecasting can provide decision-makers and the public with accurate predictions of when their health might be at risk. Research scientists, coastal users and management decision-makers must work closely together to identify the types of forecasting as well as the time and space scales that are required to reduce the risks to human health. Predicting the human health effects from poor water quality contaminants, waterborne pathogens or harmful algal blooms requires an integrated scientific approach that incorporates the disciplines of hydrology, climatology, meteorology hydrodynamics and microbiology, which is embedded in CEGLHH's research tasks. Process-level ecological models and forecasting methods are being closely linked to coastal observing systems that serve to drive and validate the models. To develop such capabilities our research is focused on prediction rather than explanation.

A combined approach of research, education, management, and outreach involving multiple partners is being used. Our main research tasks include defining 1) sources and loadings, 2) virus transport, 3) microbial research, 4) near shore transport, and 5) ecosystem and harmful algal blooms. The research includes laboratory work, field experimentation, and computer modeling. Research employs and is developing a host of new technologies and capabilities that will be useful to beach and coastal zone managers, and public health officials. Outreach activities are coordinated through the well-established Great Lakes Sea Grant Extension Program and include a broad range of activities such as needs assessment workshops, public-access website, newsletters, information-sharing partnerships, publications, and public presentations. Strong collaboration and coordination with local water quality managers at state and local levels is underway through our outreach.

The Center has organized and will chair two scientific sessions at the annual meeting of the International Association for Great Lakes Research on “Great Lakes and Human Health” and “Harmful Algal Blooms” in May 2006. The purpose of these sessions is to bring together Great Lakes scientists to enhance collaboration and to discuss how ecosystem forecasting can mediate the exposure of humans to risks due to drinking and recreation in the Great Lakes. Ecosystem forecasting can allow beach managers, water quality experts, public health policy makers provide the public with accurate predictions of when water quality could affect their health and locate the source of toxins. Understanding human health effects from poor water quality, including waterborne microbial pathogens, requires an integrated scientific approach that incorporates the disciplines of hydrology, climate, meteorology, hydrodynamics, and microbiology. In addition, the ability to communicate the risks to human health to multiple stakeholder groups requires strong training in human dimensions.

In the following sections we present each research task and the corresponding research projects that have been developed in order to address each task. The rationale for each project, progress in 2005, and statement of work for 2006 are presented in the project summaries (Appendices A-J), including PI names, project names, and the resources allocated to each project. Detailed information on each specific research project funded by CEGLHH is listed in the Appendices.

Research Task 1) Watershed Influences on Coastal Environments: Characterization of Sources and Loadings

Employing an ecosystem approach is necessary in order to fully understand the relationship between land-use and human health. Linking the influences terrestrial and coastal ecosystems have on each other leads to increased knowledge on the relationship between water quality and potential human health risks. One of the overall goals for the Center is to develop better models for prediction of water quality impacts associated with pathogens in the Great Lakes due to septic tanks and combined sewer overflows. Surface water inputs vary with tributary size and groundwater inputs vary with near-shore topographic features. Contamination effects are related to the levels of human activity in watersheds and the position of inland lakes and wetlands. We are developing an integrated monitoring and modeling framework that encompasses all dynamically relevant spatio-temporal scales to better understand coupling between land and coastal environments via groundwater and surface water. A fundamental objective of research task 1 is to extend and adapt GLERL's Large Basin Runoff Model (LBRM) for depiction and predictions of spatial surface and subsurface storages and flows to support forecasting of storm water, sewage, nutrients, contaminants, and microbial loadings from non-point sources. This would help define hydrologic pathways from land surface to the lake, prediction of magnitude and timing of flow events and how development and climate change interact to alter flow regimes (especially maximum flow rate), and support of viral transport models and research on the effects of surface water hydrology on virus transport.

2005 Milestones and Progress: We developed an integrated, spatially distributed, physically-based water quality model to evaluate both agricultural non-point source loadings from soil erosion, animal manure, and pesticides, and point source loadings at the watershed level. We augmented an existing physically based distributed surface/subsurface hydrology model (Distributed Large Basin Runoff Model) by adding material transport capabilities to it and by

expanding from a daily model to hourly. This will facilitate effective Great Lakes watershed management decision-making, by allowing identification of critical risk areas for implementation of water quality programs, and will augment ecological prediction efforts. We have applied the model to real-world data for some or all watersheds of Saginaw Bay, Grand River (Michigan), Muskegon River, Milwaukee River, Maumee River, and Sandusky River, to illustrate its use and to produce estimates useful to other ecological system forecasters. This will enhance our predictive capability in ecosystem forecasting.

We made the lumped-parameter Large Basin Runoff Model (LBRM) into a two-dimensional, spatially-distributed model (DLBRM), and applied it to the Kalamazoo River watershed in Michigan and to the Maumee River watershed in Ohio. The simulations show that the Kalamazoo River has dominant groundwater storage, allowing delayed and sustained hydrologic responses to rainfall while the Maumee River lacks any significant groundwater storage, allowing fast response to rainfall. These results are characteristic of the study watersheds. The model addition of subsurface intraflows has improved watershed representation. We modified the LBRM continuity equations for these additional flows and added corresponding corrector terms to the original solution equations; last year we replaced the analytical solution with a numerical one, demonstrating convergence. The LBRM automatically arranges cell computations from the application flow network. We reviewed available watershed water quality models. We applied the DLBRM to several new Great Lakes watersheds; we discretized and compiled databases of watershed characteristics and meteorology for 18 watersheds and calibrated the daily model to nine. We began expanding the DLBRM by adding material transport capabilities to it (conservative pollutant). We also began modifying the model from a daily time step to an hourly one and gathering information on Saginaw Bay watershed pollutants. Finally, we compared model predictions on the Maumee with an experimental field study of the movement of SF₆.

We completed discretization of 18 watersheds. We compiled databases at 1 km² resolution of elevation, slope, flow direction, soil texture, upper and lower soil thickness, water holding capacity, permeability, and land use/cover. We derived surface/channel flow roughness from slope and land use information. The watersheds are: Kalamazoo, Maumee, Sandusky, Saginaw, AuGres-Rifle, Kawkawlin-Pine, Pigeon-Wiscoggin, Tahquamenon, Grand (Erie), Genesee, Grand (Michigan), Muskegon, Clinton, Huron, Raisin, Fox, St. Joseph, and Milwaukee. We acquired and reduced all daily meteorology and flow data for all of these watersheds for the period 1948-2004 for each square kilometer of each watershed. To speed up calibrations, GLERL preprocesses all meteorology for all watershed cells and preloads it into computer memory. GLERL completed calibrations for the following 9 watersheds: Kalamazoo, Maumee, Sandusky, Saginaw, AuGres-Rifle, Kawkawlin-Pine, Pigeon-Wiscoggin, Grand (Michigan), and the St. Joseph. We completed animations of water movement on 8 of these watersheds (all but St. Joseph).

Proposed Work for 2006: Continue to use hourly data in calibrations to daily and hourly flows; extend hourly calibrations from the Maumee (currently underway) to other watersheds. Survey available information on movement of chemicals and sediment in watersheds where we have calibrations. In particular, survey the Grand River watershed (flowing into Lake Michigan) and, resources permitting, the Maumee River watershed to determine point and non-point sources of pollutants and erosion, for use in making Grand River and Maumee

predictions. Expand the DLBRM to include movement of other materials besides a conservative pollutant: sediment, chemicals, and microbes. In particular, add erosion and sedimentation mechanics to the DLBRM including modeling additions, calibration, and revised universal soil loss equation, version 2 (RUSLE2) parameter acquisitions for the Maumee River, Grand River, and Saginaw Bay watersheds. Identify flow regulation points, combined sewer outflows, and other point sources of material within the watersheds and incorporate into the model. Incorporate the real-world information on some of these materials, collected last year for the Saginaw Bay watersheds, to calibrate and use the DLBRM to simulate known cases of chemical and sediment movement. Simulate movement of specific materials into Saginaw Bay, Lake Michigan, and Lake Erie. Map DLBRM-water quality outputs over the watershed and build animations for analysis and display of results. Finally, use the model on selected Lake Erie watersheds in a hindcast mode to estimate the contribution of each cell in the watershed to the total outflow into Lake Erie on selected dates for various flow times. This will be used in connection with the forecasting of “Resource Sheds” associated with each point in Lake Erie as a function of time. For additional information, please refer to Croley Project Summary (Appendix A).

**Research Task 2) Virus Transport: Integrating Laboratory and Field-Scale Observations
with Modeling
&
Research Task 3) Microbial Approaches, Tools, and Risk Models**

Our primary objectives with research tasks 2 & 3 are to develop insights into basic processes that control large-scale virus export and transport and to quantify fluxes to the Great Lakes using process-based models. Virus transport is controlled by mechanical dispersion, preferential flow, time-dependent nonreversible and reversible attachment, and apparent mass transfer to immobile domains within the aquifer. Successful modeling requires separation of viral specific properties from lumped transport parameters. Our working hypothesis is that viral and bacterial transport is controlled by physical and chemical heterogeneity. We are using viral tracer studies and transport modeling to examine the impact of septic tanks along the diversity of Great Lakes shorelines. Our key questions are related to the level of characterization required to develop an accurate virus transport model and to the factors that influence scale-up as we move from the laboratory to a field setting.

Understanding seasonal precipitation and temperature impacts on both survival and transport are key issues. In addition, the unique features of the various lakes and their shorelines and the differences in model outcomes are being examined. These models will be coupled with larger scale models of the Great Lakes transport system to examine impact to nearby water supplies. Impact on groundwater supplies is also of concern in some areas. The ultimate goal is to predict human health risks based on urbanization, housing characteristics, soil characteristics, shore characteristics, water supply type and climate.

Advances in microbiology have led to the ability to better define the microbial hazards, the sources, transport, exposure and potential risk. The MSU and USGS team of microbiologists have been involved in the development and application of methods for environmental samples including water, groundwater, wastewater and sediments to measure bacteria, protozoa and viruses that will be used within the Center. These include:

- Methods for recovery, detection, measuring the infectivity and identifying the genotype of *Cryptosporidium*;
- Adsorption/elution methods for recovery of animal and human enteric virus isolation, cell culture and PCR methods for enumeration and differentiation.
- Bacterial source tracking with *E.coli* and *Enterococci*, through examination of near-shore transport in association with forecasting beach closures.
- Use of bacterial phage tracers in field studies associated with wastewater disposal and septic tank Both near-shore processes and a better understanding of groundwater to surface water fluxes will be investigated using this microbial approach
- Quantitative microbial risk assessment will be used as the process of integrating the scientific data regarding the microbial hazard from an environmental perspective into a framework to address the risk of exposure and the potential health impacts.

2005 Milestones and Progress

- **An Examination of Recreational Beach Waters at Huntington Beach, Lake Erie, OH, Washington Park Beach, Lake Michigan, IN and Silver Beach, Lake Michigan, MI for the Presence of Enteric Viruses and a Human Specific Gene Marker in *Enterococci*:** Cultivable enteric viruses were found in 4/24 Huntington Beach and 16/30 Silver Beach samples demonstrating the presence of fecal contamination of these waters. Water samples were screened for the presence of the *esp* gene, a human pollution marker within the *Enterococci* family. Huntington Beach: 48% of samples were found to contain the human fecal pollution marker. Silver Beach: 3.5% of samples were found to contain this marker. Pollution source identification will enable beach managers to assess risk to human health from use of these recreational waters, and aid in watershed management to minimize this risk and mitigate pollution sources. Washington Park Beach: 12% of samples were found to contain the human fecal pollution marker. Note: Viral analysis of Washington Park Beach is currently underway. For additional information, please refer to MSU Project Summary (Appendix B).
Presentations:
 - 1) "Characterization of Fecal Pollution and Human Health Risks in the Waters of the Great Lakes". J.B. Rose, S.L. Molloy, L. Liu, T.M. Jenkins, M. Wong, T.T. Fong, R.L. Whitman, D.A. Shively, M.B. Nevers, and M.S. Phanikumar, (2005), Estuarine Interactions: Biological-Physical Feedbacks and Adaptations, Estuarine Research Federation (ERF 2005) Conference, Norfolk, Virginia
 - 2) "Microbial Pollution Source Tracking Approaches at Great Lakes Beaches, USA". S.L. Molloy, T.M. Jenkins and J.B. Rose (2005), IWA Water Micro 05, Swansea, Wales
- **Groundwater Quality Investigation, Put-in-Bay, Lake Erie, OH:** South Bass Island, OH, with 500,000 visitors annually, is one of the main tourist destinations on Lake Erie. Contaminated groundwater was suspected to cause a gastrointestinal illness outbreak that affected approximately 1,400 people who visited this island in 2004. Multiple fecal-associated pathogens were responsible for the illnesses. Sixteen utility wells on the island were sampled for traditional and alternative indicator organisms as well as pathogenic organisms. The results of this study showed that groundwater on South Bass Island on Lake Erie was heavily contaminated by human enteric organisms and aided government officials

in the management of this incident and also of this important drinking water source. Satellite data showed an inflow of inorganic materials into Lake Erie impacting the Island in May, followed by biological blooms. This was after a major rainfall in May. The Lake Erie hydrodynamic model demonstrated a complex pattern of water movement around the island, and it is highly likely that there was major connectivity between the surface and groundwaters from east to west and west to east proceeding and during the outbreak. Pathogens from sewage discharges and septic tank effluents then transported through out the ground water causing massive contamination as shown by the wastewater indicators data. For additional information, please refer to MSU Project Summary (Appendix B).

Presentations: “Detection of Bacterial Indicators and Pathogenic Microorganisms from Groundwater on South Bass Island, OH”. S. L. Molloy, T. T. Fong, D. L. Wilson, L. S. Mansfield, J. B. Rose. 105th General Meeting of the American Society for Microbiology. Atlanta, GA

Publications: “Microbiological Groundwater Contamination Associated with a Massive Waterborne Outbreak in Put-in-Bay in Lake Erie, OH”. T-T Fong, S. L. Molloy, L. Mansfield, D. J. Schwab and J.B. Rose. (2005, in preparation).

- **Understanding the role of sediments in serving as reservoirs for bacteria and pathogens:** Sediments and overlying water are being sampled monthly (beginning August 2005) throughout the year along the lower Grand River, which drains into Lake Michigan, to determine the presence and abundance of fecal pollution indicator organisms. Laboratory flume studies are being conducted to provide an understanding of sediment/microorganism settling and resuspension rates as affected by overlying water flow rate. The role of suspended sediment dynamics in the river is also being investigated by combining information obtained from the backscatter of an Acoustic Doppler Current Profiler (ADCP) with traditional analyses of total suspended solids (TSS) based on water samples collected from the same locations where ADCP surveys were conducted. These studies are expected to provide quantitative estimates of sediment flux in the Grand River as well as information on the spatiotemporal variation of TSS which is important information for the modeling effort. For additional information, please refer to MSU Project Summary (Appendix B).

Presentations:

- 1) “Investigation of bacterial fecal indicators and coliphage in sediments and water along the Grand River, Michigan”. S. Singh, Fisheries and Wildlife Seminar Series, October 7th, 2005.

- 2) S. Singh et al (2005), IWA Water Micro 05, Swansea, Wales

Proposed Work for 2006: Michigan State University’s research team summarized their detailed research plans in Appendix B. We have listed a general description of their intended objectives. *Cryptosporidium* isolated from the Grand River and CSO discharges will be genotyped to aid in pollution source characterization. Laboratory flume experiments to examine the deposition and resuspension of bacteria and viruses in sediment underlying river systems will be conducted. A hydrodynamic and tracer study will be conducted on the lower Grand River to understand transport and fate of microbial pollution indicators and pathogens. The pollution transport and fate modeling effort will continue and expand with development of the 2D models into 3D models which incorporate the vertical losses and inputs between the water column and the underlying sediments. The seasonal dynamics of total suspended solids and the sediment flux exported to Lake Michigan will be calculated. Models that integrate

watershed-scale influences with in-channel processes including settling and resuspension will be further developed and refined in 2007.

- **Fecal transport modeling in Lake Michigan:** We have sampled 16 sites within the Little Calumet River/Burns Ditch watershed in NW Indiana, which drains into Lake Michigan, in coordination with GLERL, Michigan State University, and USGS, 4 times, under varying hydrologic conditions in order to model transport and fate of fecal pollution indicators in Lake Michigan. We analyzed the samples for specific nutrients and water chemistry, *E.coli* and *Enterococci*, the presence of the *Enterococcus* human fecal pollution marker, constituents of wastewater streams that may indicate type or degree of human waste contribution to water (selected sites on 3 sampling dates), and Atrazine, a ubiquitous indicator of agricultural inputs to water. We have also developed GIS coverages for the sampling sites and the datasets from the four samplings. We have developed preliminary scatterplot analyses of the data, preparatory for various multivariate statistical analyses of relations among the variables (including stream flow, and geographic/GIS variables) All the required data to build a watershed model for the study area have been compiled in the SWAT (Soil Water Assessment Tool) model, in order to identify and predict discharge at all sampling sites under varying hydrologic conditions, to serve as a building block for models in which indicator bacteria and pathogens can be related to flow. For additional information, please refer to Haack Project Summary (Appendix D).

Proposed Work for 2006: Link SWAT model to lake circulation and bacterial decay models being developed by other CEGLHH PIs. Conduct one or two samplings under combined sewer overflow conditions (CSO) to identify and understand CSO contribution of bacteria and pathogens into watershed.

- **Modeling Near-Shore Circulation and Transport:** Finite-element models of wind-driven circulation and transport in the near-shore zone for Lake Michigan have been developed and tested against data collected. In order to model transport and fate of fecal pollution indicators in Lake Michigan, samples were collected at three Lake Michigan beaches and two tributaries draining into Lake Michigan. MSU, in conjunction with USGS, collected surface water samples for enumeration of *E. coli* and *Enterococci* and human enteric viruses, and for analysis for the *Enterococcus esp* human fecal pollution marker for development and testing of the model. These models will be useful in predicting beach water quality under specific environmental conditions and are expected to be useful to recreational beach managers. Results of 2004 model development have been published in peer-review journal. Beach managers were provided with predicted *E. coli* measurement daily in 2005 to incorporate into their beach management approach (Project SAFE)

Presentations:

- 1) "Modeling the Fate and Transport of Fecal Contaminants in Near-Shore Area of the Trail Creek, Southern Lake Michigan". L. Liu, S.L. Molloy, M.S. Phanikumar and J.B. Rose, (2005) State of Lake Michigan 2005/Great Lakes Beach Association 5th Annual Meeting, Green Bay, Wisconsin
- 2) "The Presence and Near-shore Transport of Human Fecal Pollution in Lake Michigan Beaches". S. L. Molloy, L.B. Liu, M. S. Phanikumar, T. M. Jenkins, M.V. Wong and J.B. Rose (2005), Oceans 2005, Washington D.C.

- 3) Results were presented at the 2005 American Society for Microbiology General Meeting, Atlanta, Georgia, June 5-9 and at the 2005 State of Lake Michigan/Great Lakes Beach Association meeting in Green Bay, Wisconsin, November 2-3.

Publications: "Modeling the Transport and Inactivation of *E. coli* and *Enterococci* in the Near-Shore Region of Lake Michigan". L. Liu, M.S. Phanikumar, S.L. Molloy, R.L. Whitman, D.A. Shively, M.B. Nevers, D.J. Schwab and J.B. Rose, Environmental Science and Technology (2006, Environmental Science and Technology, in review)

Proposed Work for 2006: Further validation of Project SAFE predictive modeling for beach closures of Gary beaches. Water sampling analysis for *E. coli* within Burns Ditch and approximately 5 or 6 downstream beaches, and incorporation of meteorological data and current information into Project SAFE model. For additional information please refer to Whitman Project Summary (Appendix C).

Research Task 4) Near-Shore Transport: Modeling, Observations, and Beach Closure Forecasting

● **Burns Ditch Experiments:** The Great Lakes are susceptible to the introduction of pathogens from a variety of sources. Consequently water quality managers and other planning and decision entities are increasingly calling for up-to-the-minute data on present water quality conditions or forecasts of these data that can be used to adjust or respond to quickly developing activities with environmental implications. Our objectives are to:

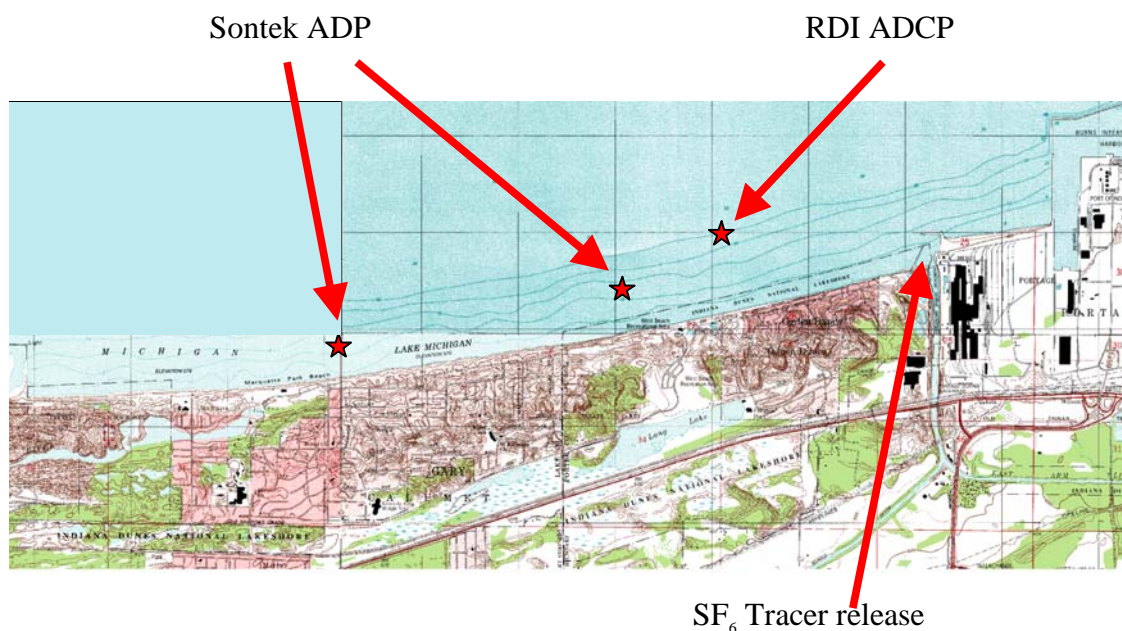
1. Develop a modeling system based upon a fully three-dimensional hydrodynamic model (Great Lakes Forecasting Model) for forecasting *E. coli* and *Enterococci* concentrations along Great Lakes coasts impacted by a specific plume (ultimately pathogens).
2. Design the modeling system and nested grid for ease of application to other sites in the Great Lakes.
3. Test model adequacy with extensive comparisons to data obtained from moored current meters, dye studies, and in situ water quality sampling.
4. Determine the extent of ecological consequences from model simulations under various weather and loading conditions and if a well-constrained set of ecological outcomes exists.
5. If fully successful, develop a training program for potential users.

2005 Milestones and Progress: In 2005, we began to develop the hydrodynamic modeling approach for linking 2 km resolution lake-scale hydrodynamic simulations with a nested local grid (covering on the order of 25 km of shoreline with a horizontal resolution of 100 m). Results from the whole-lake simulations are used to specify the open water boundary conditions for the nested grid simulations. All modeling modifications and implementations will be performed so as to maximize the ease of applying it to other Great Lakes sites in the future. The success of this proposed research will depend upon the ability of the model to accurately track the contaminant plumes and describe their interaction with coastal dynamics. In addition to the simulation with actual Lake Michigan bathymetry, we have implemented the nested grid scheme for an idealized geometry (circular basin, 100km diameter) with a nested

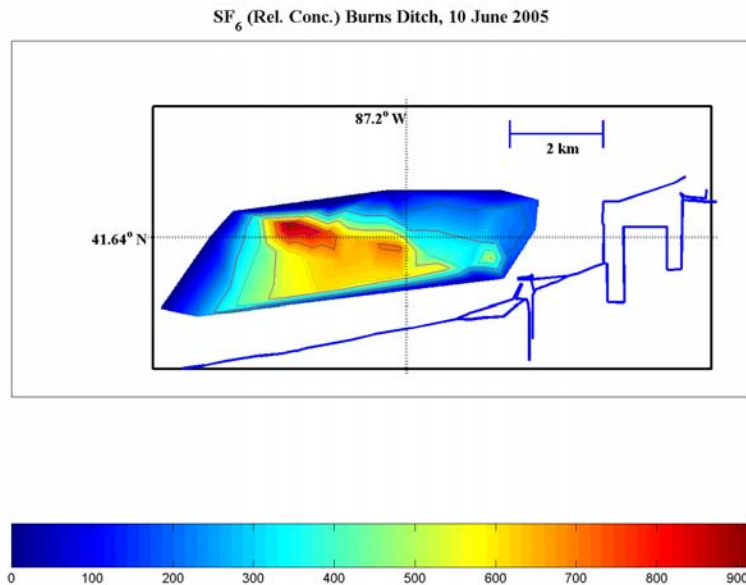
grid size of 24km x 6km with 200m horizontal resolution. The idealized bathymetry case is being used to test the accuracy of the nested grid simulation scheme.

Field activities included deployment of three acoustic Doppler current profilers and a tracer release experiment in the vicinity of Burns Ditch, Indiana. This tributary to Lake Michigan is known to contain high levels of coliform bacteria and is adjacent to the Indiana Dunes National Lakeshore. In the tracer experiment, the inert gas sulfur hexafluoride (SF_6) was introduced into the tributary and the plume was tracked using a shipboard-based gas chromatography system for several days after the release. The results of the experiment will be compared to the acoustic Doppler current meter measurements and will then be used as a test case for the hydrodynamic nested grid model.

2005 Burns Ditch Deployment



Currents and waves were recorded continuously during May-November, 2005 at three locations in the Burns Ditch area. The RDI ADCP was at 10 m water depth and the Sontek ADPs were at 5 m. Currents are generally parallel to the shore and reverse direction in response to wind events. Current magnitudes are typically 5-10 cm/s but can reach 30 cm/s during storms. Waves in this area are generally low during the summer. In 2005, waveheight exceeded 1 m only twice during the summer. During the fall, waveheight exceeded 1 m on 10 occasions and exceeded 2 m at least three times.



Sulphur hexafluoride (SF₆) was released in the vicinity of the breakwater and mouth of Burns Ditch on 9 June 2005. SF₆ was pumped into the water for one hour (1830 – 1930 EDT) and the initial patch covered an area of approximately 100 m. The following day the SF₆ patch was reacquired 16 h later and mapped for the next 7 h (1100 – 1800 EDT) aboard a research vessel equipped with near real-time processing. The leading edge of the patch moved nearly 6 km NW with sharp frontal boundaries on the offshore side. Significant dispersion of SF₆ occurred during the course of the experiment but additional comparisons with fixed current meter data are required to evaluate the extent of potential aliasing because of the long time required to produce the map.

A strategy for developing a nested-grid hydrodynamic model which can be used to forecast nearshore currents has been developed. The modeling approach depends on linking a high-resolution nearshore hydrodynamic model with operational forecasts of whole-lake circulation. An advection diffusion model is then used to simulate the dispersion of contaminants. A field experiment was carried out in 2005 to provide calibration and validation data for the hydrodynamic model. We have only just begun to compare data from the field experiment to model results, but initial comparisons are encouraging. For additional information, please refer to Schwab project summary (Appendix E).

- Virtual Beach Model:** Current methods for assessing recreational water quality are based on concentrations of *Escherichia coli* (*E. coli*) or enterococci. These take at least 18 hours to complete—too long a lapse between sampling and analytical results to be relevant to water-resource managers and the public. Mathematical models based on water-quality and environmental surrogates may be able to provide an assessment of water quality within a few hours. Beach managers and public-health officials a tool and guidance for developing beach-specific predictive models at their own local beaches. The USEPA, Office of Research Development, is working on developing such a tool called “Virtual Beach.” Because of considerable experience in developing predictive models and working with local beach managers, the USGS is collaborating with USEPA to incorporate empirical modeling

procedures into Virtual Beach. Data from beaches along the Lake Erie coastline will be used for model development and testing.

2005 Milestones and Progress: Virtual Beach Windows-based modeling framework was designed and programmed. Empirical model tab using multivariate linear regression statistical techniques developed and programmed. A preliminary dataset from Huntington, Bay Village, Ohio was provided to USEPA for model development. Rob Darner tested the latest version of Virtual Beach and provided suggestions for revisions. Test version of Virtual Beach empirical model using multivariate linear regression statistical techniques has been developed and presented to selected USGS users. Preparation of manuscript entitled “Modeling E.coli at two Lake Michigan beaches with the separate and combined influence of two point-source creek outfalls.” For additional information, please refer to Frick Project Summary (Appendix F).
Proposed Work for 2006: Conduct field experiments and compare these measurements to modeling results for model validation. Due to funding limitations we will only conduct beach closure field experiment at one location. We also intend to integrate the nearshore hydrodynamics model with other CEGLEH PI models and the Great Lakes Forecasting System.

Research Task 5) Ecosystem Research and Harmful Algal Blooms

The presence of cyanobacterial harmful algal blooms (HABs) in the Great Lakes is of considerable concern due to their ability to produce toxins that can be detrimental to human and ecosystem health. *Microcystis aeruginosa* is the dominant bloom-forming cyanobacteria in this system and produces the hepatotoxin microcystin. Microcystin concentrations higher than the World Health Organization's (WHO) recommended limit for drinking water ($1 \mu\text{g L}^{-1}$) were found throughout western Lake Erie and Saginaw Bay during the summers of 2004 and 2005 and concentrations exceeding $200 \mu\text{g L}^{-1}$ (ten times the WHO's recommended limit of $20 \mu\text{g L}^{-1}$ microcystin for recreational use) were measured in inland lakes and surface scums. The objectives of this project are to determine the distribution of *Microcystis* cells and microcystin concentrations in western Lake Erie and Saginaw Bay, develop methods for detection of toxic strains and investigate the role of environmental factors in inducing toxin production in *Microcystis*. The overall goal is to provide environmental regulators and public health officials guidance as to when microcystin toxicity is most likely to adversely affect human health.

The research at the Center is focusing on the determining factors (physiological, environmental, and genetic) controlling production of toxins by cyanobacteria in the Great Lakes. Initial focus is on the toxic chemical, microcystin produced by *Microcystis*. The central question that is guiding task 5 is: What is (are) the dominant factor(s) controlling microcystin production? The large variations in microcystin production noted for *Microcystis* generally have been attributed to growth rate/phase, environmental factors and/or genetics (strain type). Combinations of environmental factors likely 'trigger' the initiation and toxicity of a particular bloom event and attempts to delineate key endogenous factors (e.g. light utilization, nutritional status, etc.) regulating cell growth/division and/or microcystin cell quota of *Microcystis* must include evaluation of the cellular and genetic constraints for specific populations (after Millie et al. 1999). Further, the genetic potential for toxin production (via molecular regulation of

toxin genes) within natural populations must be related to both physiological and environmental processes. Specifically, we will address two hypotheses:

1. For natural populations of *Microcystis*, microcystin production is strongly linked to cell division/growth and microcystin cell quota exhibits limited variation (2-3X or less).
2. Natural populations of *Microcystis* are genetically diverse and the proportion of toxic genotypes and/or the transcription levels of toxin genes correspond with overall toxin concentrations per unit biomass within natural populations.

We are relating the amount of microcystin per unit biomass to growth rate and to both the overall genetic diversity within a population and the proportion of the population carrying the genetic machinery to produce toxin. Genetic diversity of the population is being assessed using a genetic fingerprinting technique on individual colonies.

We will continue our event response sampling during the summer of 2006. We will use satellite imagery to detect high regions of chlorophyll *a* and, when these regions develop, will sample these regions using small vessels. Samples will be assessed microscopically to determine if *Microcystis* is present and, if it is, microcystin concentrations will be determined using the ELISA assay that has been used successfully in our previous analyses. If there are high densities of *Microcystis* in inland lakes near the southern shores of Lake Michigan, microcystin concentrations will also be measured in these locations. These microcystin concentrations will continue to be posted on the HAB Bloom Response page on the GLERL website: <http://www.glerl.noaa.gov/res/Centers/HumanHealth/hab/EventResponse/>. In addition, Centers for Disease Control and Prevention (CDC) is developing an epidemiological study to complement CEGLHH's HAB research. CEGLHH will be working with the CDC to develop informational pamphlets to disseminate to the public at the sites where the epidemiological study will take place to raise awareness on potential health risks associated with harmful algal blooms.

Our understanding of factors controlling microcystin production will feed modeling/forecasting efforts directed towards microcystin occurrence and distribution throughout the Great Lakes a goal of NOAA-GLERL's internal ECOHAB program. Specifically, data generated will 'initialize' variables within mechanistic models defining the time-dependent, spatial fields of cyanobacterial abundance and toxicity throughout the Great Lakes. For additional information, please refer to Appendices G-J.

2005 Milestones and Progress: Monitoring and mapping of *Microcystis* blooms in western Lake Erie and Saginaw Bay took place during summer of 2005. Daily remote sensing images of chlorophyll were analyzed and during significant chlorophyll concentrations, samples of the bloom were collected. Preliminary results from six field experiments in which *Microcystis* populations were subjected varying environmental factors suggests the influence of light and nutrients on cellular microcystin concentrations. PCR-based assay was developed to determine if *Microcystis* colonies were comprised of toxic or non-toxic strains. Development of Harmful Algal Bloom Event Response website, which was used to post microcystin concentrations of samples. The email listserv "Habcomm" was also created to enable collaboration and education between people interested in learning about HABS in the Great Lakes region.

Proposed Work for 2006: We will conduct further research in order to identify specific effects of light and phosphorus on microcystin concentrations as well as distinguishing which environmental variable has more control over microcystin cells. Identify genetic variability of toxic *Microcystis* colonies in biweekly samples. Determination of the temporal distribution of toxic *Microcystis* strains in western Lake Erie and Saginaw Bay. Researchers with CEGLHH will continue to use a multidisciplinary approach to understand and forecast coastal-related human health impacts, including those resulting from *Microcystis* and other cyanobacterial HABs in the Great Lakes.

Outreach and Education Activities

Outreach efforts in 2005 were extremely successful. The Center of Excellence for Great Lakes and Human Health website was created, as well as an informational brochure about the Center and a brochure on Harmful Algal Blooms. The Center has been involved in planning and collaborations with USGS and EPA on developing training workshops on beach health and beach management. Search for a full-time Sea Grant Extension Agent Outreach Coordinator were completed in 2005. The Sea Grant Extension Agent began working with the Center in November 2005.

In July 2005, Laura Florence, from the CEGLHH and CILER, attended and presented on the Center's education and outreach activities at the National Marine Educators Association 2005 Conference. The Great Lakes Radio Consortium, which is a news service committed to revealing the relationship between the natural world and the everyday lives of people in the Great Lakes region, launched a "Ten Threats to the Great Lakes" News Series in October 2005. The Ten Threats series presented in-depth information about key issues affecting the Great Lakes. Two CEGLHH PIs, Dr. Joan Rose and Dr. Richard Whitman, were featured during the series on the "Bacteria Hits the Beaches" segment and the "Sewage in the Lakes" segment, respectively.

Regular conference calls are being held with the CEGLHH Outreach Coordinator and the Great Lakes Human Health Network. Monthly conference calls among the three NOAA Centers of Excellence Outreach and Education Coordinators are being held to focus on national strategies and develop new ideas for regional collaboration among the three Centers. These meetings typically last one hour and are augmented by collaboration and communication via email throughout the month. Conference call participants include Ali Senauer and Deborah McArthur of Northwest Fisheries and Susan Lovelace of Hollings Marine Laboratory.

One of the main outreach goals in 2005 was to raise awareness and establish connections and partnerships with multiple stakeholder groups, while raising awareness of the Center and its research priorities throughout the Great Lakes Basin. An information-sharing partnership has been organized with the Children's Environmental Health Network, National Association of County and City Health Officials, Great Lakes Research and Education Center, the Great Lakes Regional Water Quality Program, and the Michigan Environmental Health Association, as well as a strong partnership with the Great Lakes Human Health Network.

A Seminar Series on Great Lakes and Human Health was organized in 2005. The Seminar Series brings researchers and professionals from across the country to present their research findings or information on topics related to CEGLHH's three focus areas. The goal of the Seminar Series is to promote environmental literacy and raise public awareness of current Great Lakes and Human Health related issues. The Seminars are held at the Great Lakes Environmental Research Laboratory as well as at the University of Michigan.

A Harmful Algal Bloom Event Response Website (please see <http://www.glerl.noaa.gov/res/Centers/HumanHealth/hab/EventResponse/>) was launched in May 2005 to raise public health hazard awareness after harmful algal blooms occurred on southeastern Lake Michigan and western Lake Erie. The Event Response website was created with results of NOAA's research program that focuses on understanding factors affecting toxic algal bloom growth in the Great Lakes region. Links to an algal photo gallery, results of NOAA's sampling events, as well as useful links on finding more information on the issue of harmful algal blooms are all easily accessible from the website. Listserv "Habcomm" was created in an effort to foster communication between people interested in learning about HABs in the Great Lakes region. Members of this email service include the public health community, researchers, and concerned citizens. Press releases and information were disseminated to local media on health risks associated with HABs.

CEGLHH organized and hosted a Beach Health Research Needs Workshop in collaboration with the Great Lakes Beach Association, U.S. Geological Survey, and Environmental Protection Agency in November 2005 at the end of the State of the Lake: Lake Michigan meeting in Green Bay, Wisconsin. The purpose of this workshop was to identify needs and concerns of beach managers, public health officials, and other stakeholders and define research priorities for addressing recreational water quality issues in the Great Lakes. One of the goals of the workshop was to establish collaboration between federal and state agencies, and local groups concerned with beach health. With over 40 participants, the workshop was a great success. Feedback received will help us conduct focused research and create products that are effective, while establishing strong working relationships with various stakeholder groups to assess user needs.

FY2006 Statement of Work

The National Research Council's Committee on the Ocean's Role in Human Health (NRC, 1999) summarized the importance of the Nations coasts to human health and recommended that 1) improved predictions, 2) new technologies and 3) a multidisciplinary approach to research that includes microbiology, meteorology, oceanography and the health community are critical needs to help reduce risks to human health. Nowhere are human health issues so tightly coupled to coastal regions than in the Great Lakes because of the high concentration of humans, major cities and industries in the watershed and the Great Lakes themselves provide direct drinking water to over 40 million people.

To address the importance of the Nations coasts to human health, the NOAA Center of Excellence for Great Lakes and Human Health (CEGLHH) has employed a multidisciplinary research approach to forecast threats to human health associated with beach closures, harmful algal blooms, and drinking water quality. CEGLHH was created at the NOAA Great Lakes Environmental Research Laboratory (GLERL) in June 2004 in Ann Arbor, Michigan. GLERL forms the core of the Center but there are a number of formal partnerships with universities, other federal agencies, and a broad network of human health and municipal stakeholders that comprise the Center. CEGLHH has been fully established and strong communication mechanisms are in place. The Center is led by NOAA GLERL and has 10 full partners including Michigan State University, EPA Chicago, U.S. Geological Survey, Florida Institute of Oceanography, NOAA Beaufort Laboratory, NOAA NOA Silver Spring, EPA Athens, Michigan Sea Grant Extension, University of Michigan, and the Great Lakes Human Health Network.

Intended goals for this year are to continue coordinating with the other OHH Centers with weekly Center Director conference calls and monthly Outreach and Education Coordinator conference calls. Monthly conference calls with the Great Lakes Human Health Network will continue to develop program ideas, information exchange pathways, and organize training workshops for 2006-2007. We are planning an Open House event for multiple user groups to learn more about the Center as well as meet CEGLHH researchers and learn about research projects and specific technology and tools that are being developed. This Open House will take place in late 2006 or early 2007. In addition, the CEGLHH annual newsletter is being designed and will be disseminated to multiple user groups by June 2006. The newsletter will outline research progress, accomplishments, information, upcoming workshops and outreach activities, and other CEGLHH- related events and efforts. The annual newsletter will be available electronically and in hard copy format for distribution to partners, stakeholder groups, and constituents.

An Advisory Board for CEGLHH will also be created this year. Members of the Advisory Board will primarily be members of the Great Lakes Human Health Network, but will also include a wide representation of stakeholder groups which can help guide the Center's research and aid in the determination and assessment of user needs in the Great Lakes Basin. The Advisory Board will serve to guide user needs, represent some stakeholder needs and perspectives, and guide outreach strategies. By having a diverse representation of board members from multiple levels of government, First Nations/tribes, and members with expertise

in both water and health, the responsibility of the Board will be to determine the direction in which the Center should move and decide on research priorities. The Advisory Board will meet annually but will have regular communication with CEGLHH via the Outreach Coordinator. The first meeting of the Advisory Board will take place during the CEGLHH Open House.

CEGLHH has been collaborating with EPA Region V, USGS, and the Great Lakes Beach Association in conducting needs assessments with beach managers and local health departments. In November 2006, a follow-up from the 2005 Beach Health Research Needs Workshop will take place during the Great Lakes Beach Association annual meeting in order to review progress and accomplishments from 2005 and determine which research needs that were identified in 2005 have been met, and set priorities for accomplishing research goals that have not been accomplished.

In addition, Dr. Philip Roberts, Professor of Civil and Environmental Engineering at Georgia Institute of Technology submitted a Proposal for Distinguished Scholar in Oceans and Human Health to collaborate with CEGLHH researchers to investigate and develop mathematical models of hydrodynamics of bacterial transport in coastal waters. Dr. Philip Roberts along with Dr. Rita Colwell have been selected as Distinguished Scholars in Oceans and Human Health. These models will be incorporated into and coupled with the larger-scale hydrodynamic lake models being developed by CEGLHH researchers. The main objective is to reliably predict the fate and transport of bacteria in coastal waters under wide ranges of conditions. Beginning in summer of 2006, Dr. Roberts will work closely with CEGLHH in the planning and development of mathematical models. The research will involve laboratory experiments using innovative three-dimensional laser-induced fluorescence techniques to investigate near field mixing of buoyant discharges. The field experiments will involve using various tracers, including fluorescent soluble dye and particles, and sulfur hexafluoride. The tracer particles will mimic the physical properties of bacteria in order to investigate their behavior. The buoyant particles will be used to investigate near surface transport under the influence of winds. The laboratory and field experiments will be incorporated into mathematical models of near field and surface transport. Dr. Roberts will visit GLERL for extended periods of time (approximately two months per visit) while working with CEGLHH researchers.

Center Activities to be Funded in FY06

Center activities to be funded in FY06 through OHHI are listed below. This includes the PI name, project name, and resources allocated to each project. In addition we have also included a breakdown of other expenses (such as travel) and GLERL contributions.

Dr. Tom Croley, Spatially Distributed Surface—Subsurface Watershed Hydrology Model of Water and Materials Runoff, \$91,428

Dr. Juli Dyble, Genetic and environmental factors influencing *Microcystis* bloom toxicity, \$121,759

Dr. Gary Fahnenstiel, Microcystin Concentrations in *Microcystis* in Saginaw Bay and Western Lake Erie and Factors Controlling Microcystin Production, \$105,064

Dr. Pete Landrum, Evaluation of the Hazard of *Microcystis* Blooms for Human Health, \$48,500

Dr. George Leshkevich, Development of a MODIS Image Product for Mapping Phycocyanin Pigment in Blue-Green Algal Blooms, \$13,200

Dr. Dave Schwab, Near-Shore Transport: Modeling, Observations, and Beach Closure Forecasting, \$107,000

Dr. Richard Whitman, Near Shore Beach Closure Forecasting, \$20,000

Dr. Richard Stumpf, Remote Sensing to support “Ecosystem research and Harmful Algal Blooms”, \$ 20,000

Student Fellows \$30,000

The remaining balance of \$43,049 will be used to cover travel, conference registration for Center PIs.

TOTAL: \$600,000

Additional leveraged funds: GLERL contributed \$682,307, which includes PI salaries and four externally funded projects through GLERL’s grant proposal process. The projects which received funding will build on CEGLHH’s main research foci. One of the externally funded projects will integrate remote sensing into surface water quality modeling for the prediction of beach closures and will complement our beach closure forecasting research (Principal Investigator: Stephen Vermette, \$16,945). The second project will develop a source-specific genetic marker to identify fecal contamination by wild birds, which will add to Research Task 3 Microbial Approaches, Tools and Risk Models to determine the sources of fecal pollution to Great Lakes beaches (Principal Investigator: Stephanie Molloy, \$15,100). The third project will assess the influence of trash (rubbish) in water bodies and the health threats associated with bacteria and viruses in trash and will also contribute to research in Virus Transport and Microbial Approaches, Tools, and Risk Models research tasks (Principal Investigator: Anthony Vodacek, \$25,476). The final project will assess the degree to which pre-emptive beach closures relate to bacterial exceedances (Main Principal Investigator: Tammy Steels, \$5,000). This will build on our Beach Closure Forecasting and Microbial Approaches, Tools, and Risk Models research tasks.

Center Activities Not to be Funded in 2006

As a result of the OHH reduced funding, we will be severely reducing the geographic breadth for our beach closure research. We will only be studying and focusing our beach related work to one site, near Grand Haven, Michigan, rather than studying multiple sites, including Chicago, for Research Task 4- Near Shore Transport: Modeling, Observations, and Beach Closure Forecasting. Our major university partnerships, particularly with Michigan State

University (Dr. Joan Rose's programs) will currently be funded only through December 2006. These will need to be terminated if the FY07 funding level is the same as FY06.

In addition, the following programs that we requested supplemental funding for last year were terminated. Dr. Sheridan Haack's project "Development of a Watershed-to-Very-Near-Shore Model for Microbial Pathogen Fate and Transport" and Dr. Walter Frick's project "Empirical Model Incorporation into Visual Beach" will not receive funding in 2006. Our maintenance contract with the NOAA-Beaufort Laboratory for in-house mass spectrometry capability will also be terminated. Use of an existing Surface Enhanced Laser Desorption/Ionization-Top of Flight (SELDI-TOF) mass spectrometer, and development of an 'on-a-chip' methodology to analyze intra- and extracellular microcystins and Micropatterning of antibodies on ProteinChip Arrays for Multiplied Immunoassays of Cyanotoxins, that is housed at USF will also not be funded.

Center Project Summaries

Appendix A:

Project Title: Spatially Distributed Surface—Subsurface Watershed Hydrology Model of Water and Materials Runoff

OHHI Program (within Centers of Excellence, identify the program/division/core):

Beach Closures, Water quality
Harmful Algal Blooms

Principal and Associate Investigator(s) and Organization(s):

Thomas E. Croley II, USDOC NOAA Great Lakes Environmental Research Lab.
Chansheng He, Western Michigan University

Funding Amount and Period: ~ \$38000 in 2005

Background and Rationale: Agricultural non-point source contamination of water resources by pesticides, animal wastes, and soil erosion is a major problem in much of the Great Lakes Basin. Point source contaminations, such as combined sewer outflows, also add wastes to water flows. Improper management of fertilizers, pesticides, and animal and human waste can cause increased levels of nitrogen, phosphorus, and toxic substances in both surface water and groundwater. Sediment, waste, pesticide, and nutrient loadings to surface and subsurface waters can result in oxygen depletion and eutrophication in receiving lakes, as well as secondary impacts such as harmful algal blooms and beach closings due to viral and bacterial and/or toxin delivery to affected sites. Prediction of various ecological system variables or consequences, as well as effective management of pollution at the watershed scale, require estimation of both point and non-point source material transport through a watershed by hydrological processes.

Geographic Scope: We will develop and apply a Distributed Large Basin Runoff Model (DLBRM) to Great Lakes watersheds, including around Saginaw Bay, Grand River (Michigan), Muskegon River, Milwaukee River, Maumee River, and Sandusky River, to produce estimates useful to ecological forecasters. This has relevance to the GLERL Lake Erie Integrated Effort, NOAA's Center of Excellence for Great Lakes and Human Health at GLERL, and the proposed NOAA EcoFor6 ecological forecasting project for predicting Lake Erie hypoxia and impacts. Partners include Western Michigan University, Michigan State University, University of Michigan, Heidelberg University, Environmental Protection Agency (Chicago, Athens), USGS, Florida Institute of Oceanography, NOS Beaufort Laboratory, E2 Inc., LimnoTech Inc., University of Wisconsin, and Ohio Department of Natural Resources.

Objectives: The following major objectives should enhance modeling and forecasting of watershed flows (of use in resource mapping and flood forecasting) and water quality inputs into large water bodies (of use in harmful algal bloom and beach closing forecasts):

- Develop daily and hourly spatially distributed watershed models.
- Expand to include erosion, pollutant and sediment transport, and transport of microbes.
- Apply to selected Great Lakes watersheds with ecological modelers.
- Integrate into forecasts of beach closings and harmful algal blooms.

Accomplishments/progress to Date:

- DLBRM Hydrological Development. We built the three-dimensional DLBRM, applied the daily version to nine Great Lake watersheds, and discretized watershed characteristics and compiled databases of them and of daily meteorology for these watersheds and nine more. We are now modifying the DLBRM and its calibration for an hourly time step. It will be useful to hydrological modelers, water resource managers, and ecological forecasters.
- DLBRM Water Quality Development. We expanded the DLBRM to transport conservative dissolved pollutants and reviewed watershed water quality models. We gathered information on manure, fertilizer, pesticide, and erosion for the Saginaw Bay watersheds and identified sewer overflows locations, amounts, and durations. The model will be useful to water resource managers, ecological forecasters, and both watershed and lake beach managers.

Anticipated Products and Major Findings: Products include a high spatial resolution DLBRM, applications to several Great Lakes watersheds, a water quality version, and applications to pollutant loadings observed in the real world. These are intended for hydrological modelers, water resource managers, ecological forecasters, watershed managers, and beach managers trying to forecast harmful algal blooms and beach closings.

Issues:

- Finish developing an hourly DLBRM and its calibration.
- Finish applying to Great Lakes watersheds and compiling meteorology databases.
- Gather information on manure, fertilizer, pesticide, erosion, and sewer overflows for Grand River and Maumee River watersheds.
- Install erosion and sediment transport into the DLBRM and apply to selected watersheds.
- Simulate movement of materials into Saginaw Bay, Lake Michigan, and Lake Erie.
- Add transport mechanics for other chemicals and microbes.
- Integrate with lake circulation modelers, biological modelers, and ecosystem modelers.
- Establish the framework to extend this work for other Great Lakes watersheds.

Statement of Work 2006

Project Title: Spatially Distributed Surface—Subsurface Watershed Hydrology Model of Water and Materials Runoff

OHHI Program (within Centers of Excellence, identify the program/division/core):

Beach Monitoring
Harmful Algal Blooms

Principal and Associate Investigator(s) and Organization(s):

Thomas E. Croley II, USDOC NOAA Great Lakes Environmental Research Lab.
Chansheng He, Western Michigan University

Funding Amount and Period: ~\$38000 in 2006

Background and Rationale: Agricultural non-point source contamination of water resources by pesticides, animal wastes, and soil erosion is a major problem in much of the Great Lakes Basin. Point source contaminations, such as combined sewer outflows, also add wastes to water flows. Improper management of fertilizers, pesticides, and animal and human waste can cause increased levels of nitrogen, phosphorus, and toxic substances in both surface water and groundwater. Sediment, waste, pesticide, and nutrient loadings to surface and subsurface waters can result in oxygen depletion and eutrophication in receiving lakes, as well as secondary impacts such as harmful algal blooms and beach closings due to viral and bacterial and/or toxin delivery to affected sites. Prediction of various ecological system variables or consequences, as well as effective management of pollution at the watershed scale, require estimation of both point and non-point source material transport through a watershed by hydrological processes.

We will develop an integrated, spatially distributed, physically-based water quality model to evaluate both agricultural non-point source loadings from soil erosion, animal manure, and pesticides, and point source loadings at the watershed level. We will augment an existing physically based distributed surface/subsurface hydrology model (their Distributed Large Basin Runoff Model) by adding material transport capabilities to it and by expanding from a daily model to hourly. This will facilitate effective Great Lakes watershed management decision-making, by allowing identification of critical risk areas for implementation of water quality programs, and will augment ecological prediction efforts. We will apply the model to real-world data for some or all watersheds of Saginaw Bay, Grand River (Michigan), Muskegon River, Milwaukee River, Maumee River, and Sandusky River, to illustrate its use and to produce estimates useful to other ecological system forecasters. This will augment GLERL's predictive power in ecosystem forecasting with immediate relevance to other efforts: the GLERL Lake Erie Integrated Effort, NOAA's Center of Excellence for Great Lakes and Human Health at GLERL, and the proposed EcoFor ecological forecasting project for predicting Lake Erie hypoxia and impacts.

GLERL previously made the lumped-parameter Large Basin Runoff Model (LBRM) into a two-dimensional, spatially-distributed model (DLBRM), applied to every 1 square kilometer cell of a watershed, and modified it to allow routing flows between adjacent cells' surface zones, upper soil zones, lower soil zones, and groundwater zones. We modified the LBRM continuity equations for these additional flows and added corresponding corrector terms to the

original solution equations; last year we replaced the analytical solution with a numerical one, demonstrating convergence. The LBRM automatically arranges cell computations from the application flow network. Last year GLERL and its partner, Western Michigan University, reviewed available watershed water quality models. We applied the DLBRM to several new Great Lakes watersheds; we discretized and compiled databases of watershed characteristics and meteorology for 18 watersheds and calibrated the daily model to nine. We began expanding the DLBRM by adding material transport capabilities to it (conservative pollutant). We also began modifying the model from a daily time step to an hourly one and gathering information on Saginaw Bay watershed pollutants. Finally, we compared model predictions on the Maumee with an experimental field study of the movement of SF₆.

Proposed Work. Continue to use hourly data in calibrations to daily and hourly flows; extend hourly calibrations from the Maumee (currently underway) to other watersheds. Survey available information on movement of chemicals and sediment in watersheds where we have calibrations. In particular, survey the Grand River watershed (flowing into Lake Michigan) and, resources permitting, the Maumee River watershed to determine point and non-point sources of pollutants and erosion, for use in making Grand River and Maumee predictions. Expand the DLBRM to include movement of other materials besides a conservative pollutant: sediment, chemicals, and microbes. In particular, add erosion and sedimentation mechanics to the DLBRM including modeling additions, calibration, and revised universal soil loss equation, version 2 (RUSLE2) parameter acquisitions for the Maumee River, Grand River, and Saginaw Bay watersheds. Identify flow regulation points, combined sewer outflows, and other point sources of material within the watersheds and incorporate into the model. Incorporate the real-world information on some of these materials, collected last year for the Saginaw Bay watersheds, to calibrate and use the DLBRM to simulate known cases of chemical and sediment movement. Simulate movement of specific materials into Saginaw Bay, Lake Michigan, and Lake Erie. Map DLBRM-water quality outputs over the watershed and build animations for analysis and display of results. Finally, use the model on selected Lake Erie watersheds in a hindcast mode to estimate the contribution of each cell in the watershed to the total outflow into Lake Erie on selected dates for various flow times. This will be used in connection with the forecasting of “Resource Sheds” associated with each point in Lake Erie as a function of time.

Accomplishments/progress to Date:

We completed discretization of 18 watersheds. We compiled databases at 1 km² resolution of elevation, slope, flow direction, soil texture, upper and lower soil thickness, water holding capacity, permeability, and land use/cover. We derived surface/channel flow roughness from slope and land use information. The watersheds are: Kalamazoo, Maumee, Sandusky, Saginaw, AuGres-Rifle, Kawkawlin-Pine, Pigeon-Wiscoggin, Tahquamenon, Grand (Erie), Genesee, Grand (Michigan), Muskegon, Clinton, Huron, Raisin, Fox, St. Joseph, and Milwaukee. We acquired and reduced all daily meteorology and flow data for all of these watersheds for the period 1948-2004 for each square kilometer of each watershed. To speed up calibrations, GLERL preprocesses all meteorology for all watershed cells and preloads it into computer memory. GLERL completed calibrations for the following 9 watersheds: Kalamazoo, Maumee, Sandusky, Saginaw, AuGres-Rifle, Kawkawlin-Pine, Pigeon-Wiscoggin, Grand (Michigan), and the St. Joseph. We completed animations of water movement on 8 of these watersheds (all but St. Joseph).

Model applications to other watersheds and model extensions to water quality are in order; GLERL replaced the analytical solution with a numerical one, preparatory to adding equations for materials other than water to the DLBRM, and demonstrated convergence. We also reviewed available watershed water quality models. We began expanding the DLBRM by adding material transport capabilities to it (conservative pollutant). We also began modifying the model from a daily time step to an hourly one and gathering information on Saginaw Bay watershed pollutants. Finally, we compared model predictions on the Maumee with an experimental field study of the movement of SF₆.

Proposed Deliverables and Outcomes: Products to be completed by the end of 2006 include a high spatial resolution DLBRM, applications to several Great Lakes watersheds, a water quality version, and applications to pollutant loadings observed in the real world. These are intended for hydrological modelers, water resource managers, ecological forecasters, watershed managers, and lake beach managers trying to forecast harmful algal blooms and beach closings.

Plans for 2006:

January 1, 2006	Use hourly data in calibrations to daily and hourly flows.
January 31, 2006	Extend hourly calibrations from the Maumee to other watersheds.
March 31, 2006	Expand the DLBRM to include movement of sediment, chemicals, and microbes. Add erosion and sedimentation mechanics to the DLBRM. Acquire RUSLE2 parameters for the Maumee River, Grand River, and Saginaw Bay watersheds
May 31, 2006	Incorporate surveyed information on Saginaw Bay watershed materials into the DLBRM to simulate known cases of chemical and sediment movement. Identify point sources of material within the watersheds and incorporate into the model.
June 30, 2006	Calibrate sediment/chemical transport sub models to available data on major watersheds.
July 31, 2006	Submit companion articles on 1) 2D water quality and hourly model developments (Croley lead author) and 2) application of model to Saginaw Bay watershed pollution and sediment surveys (He lead author).
September 30, 2006	Survey the Grand River watershed (flowing into Lake Michigan) sources of pollutants and erosion. Survey the Maumee River watershed sources of pollutants and erosion if resources permit.
December 31, 2006	Make Grand River and possibly Maumee River predictions. Simulate movement of available materials, from available discharge records, into Saginaw Bay, Lake Michigan, and Lake Erie.

Map DLBRM water quality watershed outputs and build animations.

Perform hindcast studies of contributions of every 16th 1-km² cell in the Maumee watershed on the 1st and 15th of each month, from 1950—1999, for previous periods of 1 day, 7 days, and 31 days, for use in interpolation of Lake Erie resource sheds into surrounding watersheds.

Extend hindcast studies of contributions to every 8th 1-km² cell in the Maumee watershed and to additional end dates and to additional previous periods, as time permits.

Appendix B:

Project Titles: MSU's contributions to Center of Excellence for Great Lakes and Human Health
ECOLOGY AND HYDROLOGY OF PATHOGENS AND HARMFUL ALGAL BLOOMS IN THE
GREAT LAKES - AN OVERVIEW OF NOAA CENTER ACTIVITIES BY MSU and MODELING
THE TRANSPORT AND INACTIVATION OF E. COLI AND ENTEROCOCCI IN THE
NEARSHORE REGION OF LAKE MICHIGAN
MANTHA PHANIKUMAR

OHHI Program (within Centers of Excellence, identify the program/division/core):
harmful algal blooms, water quality, and beach closures/ health

Principal and Associate Investigator(s) and Organization(s):

Joan Rose, Co-PI and Mantha Phanikumar, Co-PI
Jon Bartholic, Syed Hashsham, Orlando Sarnelle, John Schwartz, Rochelle Sturtevant, James
Tiedje Michigan State University

Funding Amount and Period: \$362,761 in 2005

Background and Rationale: The Great Lakes are the largest supply of freshwater in the world. They provide 56 billion gallons of water daily for municipal, agricultural, and industrial use, including drinking water for over 40 million U.S. and Canadian citizens. There are over 500 beaches along the shores of the Great Lakes used for swimming and other recreational activities. Beach closures caused by elevated bacterial levels in the water are of increasing concern to beach managers and the public. Fecal pollution of recreational waters can cause gastrointestinal disease and other infections (e.g. eye or respiratory) in beachgoers. Water quality at our nation's beaches is impacted by a variety of fecal pollution sources (e.g. agriculture, human-related, wildlife). Fecal pollution indicators, such as *Escherichia coli* and *Enterococci*, which are used to evaluate recreational water quality, are found in a variety of mammalian hosts; thus they give no indication as to the source of fecal pollution. Identification of fecal pollution source is important in assessing the risk to human health associated with water use and for the management and remediation of, beaches and contamination sources, and for the maintenance of safe drinking water supplies.

Geographic Scope: This study takes place throughout the Great Lakes region of the United States. Groundwater and drinking water studies are being conducted throughout Michigan and a disease-outbreak related study took place in Put-in-Bay on South Bass Island on Lake Erie. Pollution transport studies are concentrating on the south-east coast of Lake Michigan and on the lower Grand River watershed. Near-shore models of fecal pollution transport from rivers to and along the shoreline developed from these studies will be applicable to inland lakes throughout the United States.

Objectives:

- Genetic characterization of waterborne pathogens.
- Development and application of microbial tools for hazard identification.
- Source tracking and use at field sites.
- Microbial transport modeling.
- Surface water, groundwater and vadose zone hydrology modeling and watershed modeling
- GIS and remote sensing

- Quantitative microbial risk assessment.

Accomplishments/Progress to Date:

- Examination of Recreational Beach Waters at Huntington Beach, Lake Erie, OH, Washington Park Beach, Lake Michigan, IN and Silver Beach, Lake Michigan, MI for the Presence of Enteric Viruses and a Human Specific Gene Marker in *Enterococci*
- Groundwater Quality Investigation, Put-in-Bay, Lake Erie, OH
- CSO contributions of *Cryptosporidium* and *Giardia* to Lake Michigan
- Survival of *Cryptosporidium* in Michigan waters
- Understanding the role of sediments in serving as reservoirs for bacteria and pathogens
- Modeling Near-Shore Circulation and Transport

Anticipated Products and Major Findings:

- An understanding of the human health risks posed to waterways and beaches in the Great Lakes by the presence of viable *Cryptosporidium* and *Giardia* associated with sewage inputs and sediment accumulation levels will be valuable to regulatory agencies and park managers for water quality control in their watersheds.
- Finite-element models of wind-driven circulation and transport in the near-shore zone for Lake Michigan have been developed and are being improved as more data is collected. There is little information on near-shore transport modeling for recreational beaches at lakes and these models are expected to provide valuable predictive information on lake beach water quality to beach and watershed managers.

Statement of Work 2006

AN OVERVIEW OF NOAA CENTER ACTIVITIES BY MSU: ECOLOGY AND HYDROLOGY OF PATHOGENS AND HARMFUL ALGAL BLOOMS IN THE GREAT LAKES and MODELING THE TRANSPORT AND INACTIVATION OF E. COLI AND ENTEROCOCCI IN THE NEARSHORE REGION OF LAKE MICHIGAN

PI: Dr. Joan B. Rose, Co-PI: Dr. Phanikumar Mantha, and Dr. John D. Schwartz

Objectives and Outcomes for Year 3 (06-07)

The MSU team will be involved in supporting tasks 1, 2, 3 and 4 in Year 3. These are summarized below and our objectives and tasks for Year 3 are summarized in Table 1.

- *Cryptosporidium* isolated from the Grand River and CSO discharges will be genotyped to aid in pollution source characterization.
- Laboratory flume experiments to examine the deposition and resuspension of bacteria and viruses in sediment underlying river systems will be conducted.
- A hydrodynamic and tracer study will be conducted on the lower Grand River to understand transport and fate of microbial pollution indicators and pathogens.
- The pollution transport and fate modeling effort will continue and expand with development of the 2D models into 3D models which incorporate the vertical losses and inputs between the water column and the underlying sediments.
- The seasonal dynamics of total suspended solids and the sediment flux exported to Lake Michigan will be calculated.
- Models that integrate watershed-scale influences with in-channel processes including settling and resuspension will be further developed and refined in year 3.
- Inter-comparison of watershed models.

Research Task 1. Watershed Influences on Coastal Environments: Characterization of Sources and Loading

Climate and land-use changes will have direct and indirect effects on nutrient and pathogen levels in surface waters, which are linked to both human and ecological health. Our objective is to explore the development of a risk assessment model to examine the potential impacts of these changes on nutrient and pathogen loading to surface waters, and the associated impairment of ecological conditions and risk of waterborne disease in large Great Lakes watersheds.

Specific goals:

- (a) Development of a risk assessment model and identification of data needs.
- (b) Studies to understand dispersion and die-off kinetics in rivers under different flow conditions and model development.
- (c) Chemical and biological tracer studies on the Grand River. The study has two objectives (i) to estimate longitudinal dispersion within the stream and (ii) to quantify the influence of transient storage (hyporheic exchange with sediments and temporary detention of solutes in surface features such as eddies and pools and woody debris. Both mechanisms contribute to elongated tails in tracer breakthrough curves).

- (d) Coupling models that describe watershed-scale influences with in-channel processes such as settling and resuspension. SWAT-based watershed-scale models will be coupled with finite-volume based mechanistic models of flow and transport within the river channel. The hydrodynamic models will be based on the numerical solution of St. Venant equations. Multi-component transport models that describe the fate and transport of chemical and biological agents will use multiple source and sink terms to describe exchanges between sediment and the water column, interactions with dead zones as well as inactivation and other losses.
- (e) The seasonal dynamics of TSS (total suspended solids) concentration is important for accurately describing pathogen transport processes. ADCP surveys coupled with analysis of water samples collected at the same time will provide additional useful data.

Research Task 2. – Virus Transport: Integrating Laboratory and Field-Scale

Our objective is to develop a mechanistic understanding of the processes that control virus transport in the environment. Our approach integrates laboratory flume experiments and carefully designed field experiments with modeling to gain insights into the processes and parameters.

Long-term Objective:

- Develop tools to predict fluxes of nutrients and pathogens from the watershed(s) to the Great Lakes. Characterize sources and loading.

Specific objectives for 2006 include:

- (a) Microbial deposition and resuspension in sediment. Our aim is to develop models for virus deposition and resuspension.
Approach: 1) Conduct laboratory-scale flume studies to track the deposition and resuspension of seeded bacterial, viral and parasitic model organisms at various flow rates into and from two types of sediment commonly found in the lower Grand River watershed (sand and loamy/sand). 2) Develop high-resolution, three-dimensional flow and reactive transport models that describe the observed virus and tracer transport data in the near-shore environments - Expansion of the 2D models into 3D models which incorporate the vertical losses and inputs between the water column and the underlying sediments.
- (b) Chemical and biological tracer studies on the Grand River coupled with simultaneous hydrodynamic data collection (using ADCP and ADV surveys) and continuous monitoring for 3 days using ISCO autosamplers to accurately estimate the tail portion of breakthrough curves.
- (c) Site characterization for installation of monitoring wells to understand subsurface transport of viruses near the lake.
- (d) Collection of cores and core analysis to characterize sediment for sorption and hydraulic conductivity.
- (e) Geospatial interpolation of sorption and permeability data onto a 3D finite-difference grid for further analysis and model development.
- (f) Publications in peer-reviewed journals.

Our objectives in year 3 are: a) to develop mechanistic models that describe virus transport and inactivation in ground and surface waters in selected near-shore regions. The surface water and overland flow components of virus transport are poorly understood and received very little attention in the past. Similarly, very few studies (if any) examined transport in coastal / near-shore environments particularly during an annual cycle. Our approach will integrate laboratory column experiments and field-scale observations with high-resolution numerical modeling to understand virus and pathogen transport in ground- and surface waters. We will conduct large-scale virus transport experiments to understand the influence of physical and chemical heterogeneity on virus transport relative to the transport of a conservative tracer such as bromide or fluorescein. We will perform detailed hydrogeological and geophysical site characterization before installing a network of monitoring wells for the tracer (and bacteriophage) studies near the lake. These experiments will be designed to understand virus transport in groundwater as well as to determine concentrations at the lake. Faecal pollution of watercourses from diffuse sources could potentially become significant after storm events. There is evidence to suggest that between 4 to 32% of the annual load of faecal bacteria could be contributed to a water body during a single 12 hour event. We will conduct tracer and bacteriophage transport studies to understand the relevant processes and to aid our modeling studies.

b) Further site characterization for installation of monitoring wells to understand subsurface transport of viruses near the lake. Cores will be collected and analyzed in the environmental engineering laboratories at MSU to characterize the sediment for sorption and hydraulic conductivity. Multi-level sampling wells will be installed and subsurface tracer studies using bromide and fluorescein will be conducted in the Grand Haven/Spring Lake area to estimate dispersion and fluxes to the Lake. Future efforts will integrate this data into three-dimensional groundwater flow and transport models.

Research Task 3. - Microbial Approaches, Tools and Risk Models

Advances in microbiology have led to the ability to better define the microbial hazards, the sources, transport, exposure and potential risk. The MSU and USGS team of microbiologists have been involved in the development and application of methods for environmental samples including water, groundwater, wastewater and sediments to measure bacteria, protozoa and viruses that will be used within the Center.

Long-term Objective: To further develop key methods and apply them to field studies.

Short-term Objectives for Year 3:

a) Genetic characterization of *Cryptosporidium* associated with CSO discharges in the lower Grand River watershed. The aim of this work is to characterize *Cryptosporidium* found in lower Grand River waters to provide insight as to the source of this pathogen. There are several known species of *Cryptosporidium* that are associated with certain hosts and these can be discriminated by genotyping. For example, *C. hominis* (previously *C. parvum* genotype 1) is found in humans, while *C. parvum* (previously genotype 2) infects humans and some other mammals, including ruminants. *C. andersoni* is a species found in cattle and has been previously found in cattle and surface water from farms in the lower peninsula of Michigan.

b) Pathogen occurrence at beaches near drinking water intakes. MSU has been working with Dr. Shannon Briggs (MI DEQ), examining *E. coli* at beaches and the relationship to drinking water intakes in the state. Mapping of Michigan drinking water source intake locations along with Great Lakes beaches that exceed water quality standards indicates a potentially compromised drinking water supply and highlights the importance of good water quality at our beaches not only for recreational purposes but for other uses as well for example as a drinking water source. Samples will be collected from several of these sites around Michigan and analyzed for a suite of pathogens to characterize the microbial quality of these recreational beaches and drinking water sources.

Research Task 4. - Near-Shore Transport: Modeling, Observations, and Beach Closure Forecasting

Under the Clean water Act, the recent BEACH Act, and the TMDL rule, there has been a demonstrated need for improved monitoring for sources of human waste and for specific pathogens of concern. Human health can be explicitly tied to water quality, and despite major advances in the last several decades, fresh water systems remain at risk.

Our long term objectives for Task 4 are:

1. Develop a modeling system based upon a fully three-dimensional hydrodynamic model (GLFS) for forecasting *E. coli* and Enterococci concentrations along Great Lakes coasts impacted by a specific plume (ultimately pathogens).
2. Design the modeling system and nested grid for ease of application to other sites in the Great Lakes.
3. Test model adequacy with extensive comparisons to data obtained from moored current meters, dye studies, and in situ water quality sampling.
4. Determine the extent of ecological consequences from model simulations under various weather and loading conditions and if a well-constrained set of ecological outcomes exists.
5. If fully successful, develop a training program for potential users.

Short-term Specific objectives for year 3 are as follows:

(a) Regional modeling of transport and inactivation of *E. coli* in Southern Lake Michigan based on historical *E. coli* monitoring data for 55 beaches over a four year period. This study will allow us to understand the factors that influence background concentrations of *E. coli* in S. Lake Michigan and the effects from multiple beaches. In addition, the study is expected to shed light on unknown sources and loading for certain beaches.

(b) A near-shore field experiment (coupled physical/chemical biological experiment) will be conducted in 2006-07 to estimate turbulent mixing coefficients in the hydrodynamic models as well as parameters in the transport models (e.g., eddy diffusion).

(c) Modeling high-frequency (based on 1-hour sampling) and night-time variations of *E. coli* concentrations at the Chicago 63rd beach. This study will examine the processes that influence the observed short-term variability in *E. coli* concentrations. In the models, detailed effects of

changing current and wave patterns, sunlight and clouds and temperature effects will be included among other processes.

(d) Outcomes: An improved understanding of the processes that influence the transport and inactivation of pathogens over a range of spatial (beach-scale to regional scale) and temporal (hours to days) scales. Publications in peer-reviewed journals.

Appendix C:

Project Title: Modeling and Beach Closure Forecasting at Burns Ditch and Five Beaches

OHHI Program (within Centers of Excellence, identify the program/division/core): Great Lakes and Human Health- Beach closures

Principal and Associate Investigator(s) and Organization(s): Richard L. Whitman, US Geological Survey, Great Lakes Science Center

Funding Amount and Period: \$46,000. FY2005

Background and Rationale: Beaches along the Indiana coast of Lake Michigan have experienced an increase in the number of beach closures due to high levels of *E. coli* bacteria, an indicator of potential sewage contamination and associated pathogens. Research on Burns Ditch, Portage, Indiana, has shown that it contributes significant amounts of *E. coli* and associated bacteria to the near shore beach areas of southern Lake Michigan, but the extent of impact on the nearby beaches from increased bacteria counts has not been determined. *Escherichia coli* levels at these beaches have remained fairly stable over the years but levels are generally unpredictable. Sources and causes for the fluctuations in *E. coli* remain unknown. Beach monitoring has been sporadic (once per week), and few additional resources have been devoted to developing a more consistent, reliable monitoring program. The current monitoring program has been proven inadequate, particularly if samples are collected only periodically. The relationship between the high counts of bacteria in Burns Ditch, particularly during rain events, and *E. coli* counts at the beach has not been established, despite the known releases of untreated sewage into the waterway during measurable rainfall events. By examining indicator bacteria counts daily in Burns Ditch, and the four beaches to the west, along with ambient hydrometeorological conditions at several fixed stations, a multi-beach predictive model can be developed that characterizes *E. coli* abundance and movement.

Geographic Scope: Burns Ditch is the outfall of the Little Calumet River into Lake Michigan. Deep River and Salt Creek are important tributaries of the Little Calumet River. At the Lake Michigan outfall, Burns Ditch is directed to the west by a breakwater, and the five beaches extending to the west include: Ogden Dunes, West Beach, Wells Street Beach, Marquette Beach, and Lake Street Beaches. The study areas are located in Porter and Lake Counties, Indiana. Burns Ditch was the subject of tracer studies conducted as part of this overall project.

Objectives:

- Develop predictive model for five beaches west of Burns Ditch outfall
- Test model adequacy using statistical approach and separately collected data
- Determine variations in model outcome under different environmental conditions

Accomplishments/progress to Date:

- Results of 2004 model development have been published in peer-review journal
- Beach managers were provided with predicted *E. coli* measurement daily in 2005 to incorporate into their beach management approach (Project SAFE)

- Results were presented at the 2005 American Society for Microbiology General Meeting, Atlanta, Georgia, June 5-9 and at the 2005 State of Lake Michigan/Great Lakes Beach Association meeting in Green Bay, Wisconsin, November 2-3.

Anticipated Products and Major Findings: Results of 2004 model development have been published, which showed that models were better able to predict *E. coli* counts when winds were from the north and beaches were more impacted by the ditch. Additionally, 2005 model validation was conducted at the study locations, and results of comparisons are being prepared for publication. Daily reports of model predictions were distributed to beach managers through the 2005 study period.

Issues:

- Comparison of 2004 model with additional results for model validation

Statement of Work 2006

Project Title: Project SAFE: Modeling and Beach Closure Forecasting at Burns Ditch and Five Beaches

OHHI Program (within Centers of Excellence, identify the program/division/core): Great Lakes and Human Health- Beach Closure

Principal and Associate Investigator(s) and Organization(s): Richard L. Whitman, US Geological Survey, Great Lakes Science Center

Timeline: April 2006 to December 2006.

Deliverable: Daily estimates of E. coli concentrations at beaches immediately west of Burns Ditch. Exchange of data with NOAA.

We are in the process of developing a proposal for Indiana Department of Environmental Management to further validate project SAFE, the predictive modeling for beach closures of Gary beaches and vicinity. It is essentially a sole source contract since we developed SAFE originally and the program has been through peer review. Part of the contract would be a little supplemental funding to do some preliminary QPCR analysis on site. We have told IDEM we would be interested in pursuing the contract **only** if NOAA was involved because of the 1) information that Dave Schwab can provide the model (current and wave vectors), 2) the resulting USGS/NOAA publications and 3) the leveraged funding from the OHH program.

The QPCR gives us another dependent variable and prepares us for upcoming EPA criteria applications. The 2006 program would consist of weekday sampling of E. coli within Burns Ditch and 5-6 downstream beaches. Turbidity, color, chlorophyll would be monitored along with stream discharge. Meteorological data would be obtained by the Michigan City GLERL station. Dave would deliver to us morning current information as an input variable. Thus, the program would integrate NOAA and USGS much more fully than in earlier years and we could then explore the relative merits of statistical vs. hydrodynamic modeling or some combination.

In all, it is an ambitious program that will require partnerships with NOAA, IDEM, Gary and other local municipalities. I am asking for funding for two summer field technicians. These are nominal cost estimates made in light of the severely limited OHH budget. Travel, supplies, equipment, analytical costs, etc. will be borne by cooperators or absorbed.

Category	Items	Duration (months)	Cost/month	Total
Field Technicians-BS or above	2	4	1735.5	13884
Indirect Costs				6000
Total Requested				19884

Appendix D:

Project Title: Development of a watershed-to-very-near-shore model for microbial pathogen fate and transport.

OHHI Program: Great Lakes Center of Excellence for Human Health- Beach closures, water quality

Principal and Associate Investigator(s) and Organizations: Principal--Sheridan K. Haack, skhaack@usgs.gov, 517-887-8909; Associate--Joseph W. Duris and Atiq U. Syed; U.S. Geological Survey, Michigan Water Science Center, Lansing, MI

Funding Amount and Period: \$67,000 provided through supplemental request in FY05

Background and Rationale: One of the overall goals for the NOAA Center of Excellence for Great Lakes and Human Health is to develop better models for the prediction of the water quality impacts associated with pathogens that enter the Great Lakes from various point and nonpoint sources. Currently, most models of microbial fate and transport do not address specific pathogens, and are instead based on the fecal indicator bacteria and information on their survival, fate and transport in watersheds. The fecal indicator bacteria (*E. coli*, enterococci) are poorly representative of the survival, fate and transport of non-bacterial pathogens, such as viruses and protozoa, and their relation to bacterial pathogens is unknown. Additional problems with most current models are that they do not adequately address 1) temporal and spatial variability in source loadings of pathogens; 2) variability in the types of the pathogens delivered from various point and nonpoint sources; or 3) in-stream and very-near-shore processes that influence the delivery and fate of pathogens. Therefore, one critical component of reaching the Center's ultimate goal is to acquire specific data on and develop specific models of watershed-to-very-near-shore fate and transport of microbial pathogens that address these current inadequacies. Such information will be critical to extension and adaptation of the Large Basin Runoff Model for microbial contamination, will be helpful in linking the virus transport component of ongoing Center efforts to watershed processes, and will be useful in coupling to the in-lake transport components of the Center's effort.

Geographic Scope: The study watershed is in northeastern Indiana, tributary to southern Lake Michigan. The study watershed has been the subject of previous pathogen studies by the NOAA Great Lakes Center for Human Health co-PI, Dr. Joan Rose; of several previous studies by Dr. Richard Whitman, a Center PI, looking at the influence of the outflow on nearby beaches, and developing forecasting models for the region; and finally, is the major tributary to the portion of southern Lake Michigan being modeled by Center PI, Dr. Phanikumar Mantha. In addition, the watershed is one in which several NOAA center staff conducted an offshore SF₆ tracer study during summer 2005.

Objectives: We propose to ultimately

- 1) acquire detailed, microbe-specific, occurrence, fate and transport data in a Center focus watershed;
- 2) develop a model of watershed-to-very-near-shore transport of these microbial constituents that can be linked to other models and research within the Center.

Accomplishments/Progress to Date:

- 1) We have sampled 16 sites within the Little Calumet River/Burns Ditch watershed in NW Indiana, 4 times, under varying hydrologic conditions for
 - a. Nutrient and selected major ion chemistry and field physical conditions
 - b. Fecal indicator bacteria --fecal coliform, *E. coli* and enterococci
 - c. Nine genes indicating the presence of pathogenic *E. coli* and enterococci
 - d. "Emerging chemical wastewater contaminants" –constituents of wastewater streams that may indicate to type or degree of human waste contribution to water (selected sites on 3 sampling dates)
 - e. Atrazine, as a ubiquitous indicator of agricultural inputs to water.
- 2) We have developed GIS coverages for the sampling sites and the datasets from the four samplings
- 3) We have developed preliminary scatterplot analyses of the data, preparatory for various multivariate statistical analyses of relations among the variables (including stream flow, and geographic/GIS variables)
- 4) All the required data to build a watershed model for the study area have been compiled in the SWAT (Soil Water Assessment Tool) model, in order to identify and predict discharge at all sampling sites under varying hydrologic conditions, to serve as a building block for models in which indicator bacteria and pathogens can be related to flow.

Anticipated Products/Major Findings: The primary product we anticipate developing is, as the title indicates, a "watershed-to-very-near-shore" model of bacterial pathogen fate and transport. Such a model is an absolute requirement for developing the types of forecasting models proposed by the NOAA Great Lakes Center of Excellence for Human Health, since this would constitute the source function for both bacterial indicators of water quality and pathogens for such forecasting models.

Issues: In order to develop a complete model and link to the lake circulation models being developed by Phanikumar Mantha, we would need to do the following:

- 1) Conduct at least one, and preferably two samplings, under conditions during which combined sewer overflows are occurring, since this contribution to bacteria/pathogens in the watershed did not occur during our limited sampling period.
- 2) Develop modeling approaches to link the SWAT model we are developing to the lake circulation model Phanikumar Mantha is developing. This will require detailed discussions and interactions between Phanikumar Mantha and Atiq U. Syed. This may also require obtaining specific flow data in the complex hydrologic flow/mixing environment where Burns Ditch reaches the lake.
- 3) Considerably more analysis is required to develop a pathogen-specific model. Specifically, once the multivariate analysis is completed, relations between environmental variables and pathogen genes will suggest processes that need to be modeled in a more mechanistic manner. To do this we would use the USGS (United States Geological Survey) PRMS model (Precipitation Rainfall-Runoff Model) under the MMS (Modular Modeling System) environment, a set of modular modeling tools to

enable a user to selectively couple the most appropriate process algorithms from applicable models to create an "optimal" model for the desired application and lead to a better understanding of the pathogen fate and transport processes as they occur in the natural environment.

The *primary issue* that our current funding will take us only through this winter, and we will be unable to develop these next steps in the absence of additional funding.

Statement of Work 2006

CEGLHH Project Title: Development of a watershed-to-very-near-shore model for microbial pathogen fate and transport.

Principal and Associate Investigator(s) and Organizations: Principal--Sheridan K. Haack, skhaack@usgs.gov, 517-887-8909; Associate--Joseph W. Duris and Atiq U. Syed; U.S. Geological Survey, Michigan Water Science Center, Lansing, MI

Background and Rationale: One of the overall goals for the NOAA CEGLHH is to develop better models for the prediction of the water quality impacts associated with pathogens that enter the Great Lakes from various point and nonpoint sources. Currently, most models of microbial fate and transport do not address specific pathogens, and are instead based on the fecal indicator bacteria and information on their survival, fate and transport in watersheds. The fecal indicator bacteria (*E. coli*, enterococci) are poorly representative of the survival, fate and transport of non-bacterial pathogens, such as viruses and protozoa, and their relation to bacterial pathogens is unknown. Additional problems with most current models are that they do not adequately address 1) temporal and spatial variability in source loadings of pathogens; 2) variability in the types of the pathogens delivered from various point and nonpoint sources; or 3) in-stream and very-near-shore processes that influence the delivery and fate of pathogens. Therefore, one critical component of reaching the Center's ultimate goal is to acquire specific data on and develop specific models of watershed-to-very-near-shore fate and transport of microbial pathogens that address these current inadequacies.

Geographic Scope: The study watershed is in Indiana, tributary to southern Lake Michigan. The study watershed has been the subject of previous pathogen studies by the NOAA CEGLHH PI, Dr. Joan Rose; of several previous studies by Dr. Richard Whitman, a CEGLHH PI, looking at the influence of the outflow on nearby beaches, and developing forecasting models for the region; and finally, is the major tributary to the portion of southern Lake Michigan being modeled by CEGLHH PI, Dr. Phanikumar Mantha. In addition, the watershed was the focus of a NOAA SF₆ tracer study during summer 2005. At the recent NOAA All-PI meeting in South Carolina, CEGLHH scientists agreed that so much critical data had been acquired for this watershed that it would be the focus of data analysis and modeling during FY2006.

Objectives: We proposed to ultimately 1) acquire detailed, microbe-specific, occurrence, fate and transport data in a Center focus watershed; and 2) develop a model of watershed-to-very-near-shore transport of these microbial constituents that could be linked to other models and research within the Center.

Accomplishments/Progress to Date: With funding provided late in FY05 we have already made major accomplishments toward meeting these goals. Specifically,

- 5) We have sampled 15 sites within the Little Calumet River/Burns Ditch watershed in NW Indiana, each 4 times, under varying hydrologic conditions (base flow, rising hydrograph, falling hydrograph, and 4 days after rain) for--

- a. Nutrient and selected major ion chemistry and field physical conditions
- b. Fecal indicator bacteria --fecal coliforms, *E. coli* and enterococci
- c. Nine genes indicating the presence of potentially pathogenic *E. coli* (*rfb* O157, *stx1*, and *stx2c-f*) and enterococci (*esp*), and also providing some information with regard to source
- d. "Emerging chemical wastewater contaminants" –constituents of wastewater streams that may indicate the type or degree of human waste contribution to water (selected sites on 3 sampling dates)
- e. Atrazine, as a ubiquitous indicator of agricultural inputs to water.

The sites were selected to address various land uses within the watershed, to follow patterns of chemistry and bacterial constituents from headwaters, and to address the specific influence of known sources of contamination such as WWTP effluents.

- 6) We have developed GIS coverages for the sampling sites and the datasets from the four samplings
- 7) We have developed preliminary statistical analyses of relations among the variables
- 8) We have compiled a watershed hydrologic model in SWAT (Soil Water Assessment Tool). SWAT is a river basin scale model, developed by USDA, to quantify the impact of land management practices in large, complex watersheds. Databases used to develop the model include a Digital Elevation Model of the study area, delineated watershed boundaries, the National Hydrologic Dataset stream boundaries, land use data, soils data, point source discharges (specifically including capability to include WWTP and CSO discharges) and weather data. The model output appears to be well calibrated to flow patterns near the confluence of Burns Ditch and the Little Calumet River, and is ready for the next stage of application to water quality parameters, such as fecal indicator bacteria or chemical constituents.

Tasks for FY2006:

- 1) Conduct at least one, and preferably two samplings, under conditions during which combined sewer overflows are occurring, since this contribution to bacteria/pathogens in the watershed did not occur during our FY05 sampling period.
- 2) Conduct comprehensive statistical analysis of the large dataset we have acquired, using multivariate approaches, to establish relations between environmental and chemical variables and pathogen detections.
- 3) Link the SWAT model we have developed to the lake circulation and bacterial decay models being developed by other CEGHH PIs. The first meeting for this activity is planned for March 23 at GLERL.

Deliverables and Outcomes for FY2006 (both to be achieved by late 2006):

- a. Linkage of the Burns Ditch/Little Calumet River SWAT model to lake circulation/ bacterial decay models developed by other NOAA PIs. Specific form of the output to be determined by the investigators.
- b. A journal publication describing relations between environmental and chemical variables and pathogen detections, and significance for watershed modeling.

Appendix E:

Project Title: Near-Shore Transport: Modeling, Observations, and Beach Closure Forecasting

OHHI Program (within Centers of Excellence, identify the program/division/core): Near-Shore Transport: Modeling, Observations, and Beach Closure Forecasting- Beach closures, water quality

Principal and Associate Investigator(s) and Organization(s): David J. Schwab (NOAA/GLERL), Michael McCormick (NOAA/GLERL), Dmitry Beletsky (Univ. of Michigan/ CILER)

Funding Amount and Period: \$141,400 in 2005

Background and Rationale: Water quality managers and other planning and decision entities are increasingly calling for up-to-the-minute data on present water quality conditions or forecasts of these data that can be used to adjust or respond to quickly developing activities with environmental implications. Examples include the forecast of short term water quality conditions for the withdrawal of water for drinking water supply; short range predictions of potentially dangerous conditions at water supply intakes; the forecast of beach closings and openings from bacterial contamination from combined sewer overflow (CSO); the knowledge of the trajectory of materials from dangerous spills; short range prediction of the impact of shoreline activities at one site or another shoreline site; and the forecasting of upwelling and downwelling events and the associated nutrient and bacterial redistributions required for toxic plankton blooms. This project intends to develop predictive nearshore hydrodynamic transport models of these phenomena.

Geographic Scope: This project will be carried out mainly in the Great Lakes region, but results of nearshore field experiments and modeling studies will be relevant to all coastal regions.

Objectives:

- 1. Develop a modeling system based upon a fully three-dimensional hydrodynamic model (GLFS) for forecasting E. coli and Enterococci concentrations along Great Lakes coasts impacted by a specific plume (ultimately pathogens).*
 - 2. Design the modeling system and nested grid for ease of application to other sites in the Great Lakes.*
 - 3. Test model adequacy with extensive comparisons to data obtained from moored current meters, dye studies, and in situ water quality sampling.*
 - 4. Determine the extent of ecological consequences from model simulations under various weather and loading conditions and if a well-constrained set of ecological outcomes exists.*
 - 5. If fully successful, develop a training program for potential users.*
- These goals are all relevant to NOAA's mission of environmental prediction.*

Accomplishments/progress to Date: Progress in 2005:

1. In 2005, we began to develop the hydrodynamic modeling approach for linking 2 km resolution lake-scale hydrodynamic simulations with a nested local grid (covering on the order of 25 km of shoreline with a horizontal resolution of 100 m). Results from the whole-lake simulations are used to specify the open water boundary conditions for the nested grid simulations. All modeling modifications and implementations will be performed so as to maximize the ease of applying it to other Great Lakes sites in the future. The success of this

proposed research will depend upon the ability of the model to accurately track the contaminant plumes and describe their interaction with coastal dynamics. In addition to the simulation with actual Lake Michigan bathymetry, we have implemented the nested grid scheme for an idealized geometry (circular basin, 100km diameter) with a nested grid size of 24km x 6km with 200m horizontal resolution. The idealized bathymetry case is being used to test the accuracy of the nested grid simulation scheme.

2. Field activities included deployment of three acoustic Doppler current profilers and a dye-release experiment in the vicinity of Burns Ditch, Indiana. This tributary to Lake Michigan is known to contain high levels of coliform bacteria and is adjacent to the Indiana Dunes National Lakeshore. In the tracer experiment, the inert gas sulfur hexafluoride was introduced into the tributary and the plume was tracked using a shipboard-based gas chromatography system for several days after the release. The results of the experiment will be compared to the acoustic Doppler current meter measurements and will then be used as a test case for the hydrodynamic nested grid model.

3. Tracer studies were also conducted during the spring of 2005 in a tributary of the Maumee River. The data from this experiment are being used primarily to test and calibrate Tom Croley's distributed hydrologic model.

4. A report to Congress on the Development of Forecasting Models for Beach Closings in Southern Lake Michigan was prepared and briefed to Congressman Kirk from Illinois.

Anticipated Products and Major Findings: The purpose is to develop and test (through carefully designed field experiments) techniques for simulating and forecasting the impact of point source pollutants on near shore water quality in the Great Lakes and other coastal areas. The results of this project will be directly relevant to forecasting nearshore water quality and impacts on human health, particularly beach closure forecasting.

Issues: Identification of pathogen sources and ability to predict loadings into nearshore area.

Statement of Work 2006

Title: Research Task 4. - Near-Shore Transport: Modeling, Observations, and Beach Closure Forecasting

Principal investigator: D. Schwab (30%), M. McCormick (40%)

Co-principal Investigators: A. Yao (UM), D. Beletsky (UM), R. Whitman (USGS), W. Frick (USEPA), M. Phanikumar (MSU)

Our initial specific objectives for CEGLHH Task 4 are:

- 1. Develop a modeling system based upon a fully three-dimensional hydrodynamic model (GLFS) for forecasting E. coli and Enterococci concentrations along Great Lakes coasts impacted by a specific plume (ultimately pathogens).*
- 2. Design the modeling system and nested grid for ease of application to other sites in the Great Lakes.*
- 3. Test model adequacy with extensive comparisons to data obtained from moored current meters, dye studies, and in situ water quality sampling.*
- 4. Determine the extent of ecological consequences from model simulations under various weather and loading conditions and if a well-constrained set of ecological outcomes exists.*
- 5. If fully successful, develop a training program for potential users.*

Project Rationale

When contrasting the information needs of water quality managers with the forecasting experience to date, three issues remain. First, the information requirements all occur with regard to activities in, near, and around the near-shore/inshore zone. It is well known that the greatest demand for lake/coastal resources is in the near-shore zone and accurate information is required in this zone. Second, the information needs of the managers are for water quality data; data not yet predicted or available in forecast form. Third, the water quality forecasts require knowledge of both point and non-point sources. Our initial proposed research program will focus on point source loadings of *E. coli* (EC) into coastal environments from particular rivers and its impact on beach closures.

We will employ the Princeton Ocean Model (Blumberg and Mellor 1987) for calculation of lake-scale hydrodynamic circulation. Over the past 10 years, the Princeton hydrodynamic model has been adapted for use in the Great Lakes and has been successfully applied both for long-term climatological simulations and for use in a real-time coastal forecasting system (Schwab and Bedford 1994; Beletsky and Schwab, 2001; Beletsky et al., 2003). The model is based on the three-dimensional, nonlinear Navier-Stokes equations. It employs a terrain-following vertical coordinate (sigma coordinate) to provide high vertical resolution even in shallow areas.

For lake-scale simulations, meteorological data from the NWS surface observing stations and two mid-lake weather buoys will be used to synthesize overwater momentum flux and heat flux fields to drive the model. Previous applications of the circulation model have shown that the accuracy of the results is usually limited by the accuracy of the forcing fields (Schwab 1983, Schwab and Bennett 1987, Schwab et al. 1989, O'Connor and Schwab 1993; Beletsky et

al., 2003). Once the lake-scale simulations are completed, a nested grid with a grid size on the order of 100 m will be applied to the coastline in the specific study area (e.g. Figure 10). Results from the whole-lake simulations will be used to specify the open water boundary conditions for the nested grid simulations. All modeling modifications and implementations will be performed so as to maximize the ease of applying it to other Great Lakes sites in the future. The success of this proposed research will depend upon the ability of the model to accurately track the contaminant plumes and describe their interaction with coastal dynamics. Field activities will be concentrated in years two and three of the proposal and will focus on current meter measurements and tracer studies as well as some *in situ* water quality sampling. Three Acoustic Doppler Current Profilers (ADCP) are planned for deployment in the study site. Each ADCP will be upward looking. Although our primary emphasis is forecasting the need for beach advisories due to elevated EC concentrations during the summer months the deployment period will extend from early spring through fall. The longer current meter data set will provide more extensive conditions for model testing and development during high and low flows under both stratified and non-stratified conditions.

Tracer studies will be conducted during the spring and summer of 2005 and 2006. The spring experiment will involve tracer releases in several streams in the Maumee River basin. The data from this experiment will be used primarily to test and calibrate Tom Croley's distributed hydrologic model. The summer experimental site will be the mouth of a river entering southern Lake Michigan. Final site selection will be based upon the needs and interests of beach managers and other researchers in CEGLHH. The experimental procedure begins with injection of sulfur hexafluoride (SF₆) labeled water into the study site. The general procedure will follow that of Harden et al., (2003). Sulfur hexafluoride is a biologically and chemically inert water-soluble gas that can be detected at very low concentrations (10^{-16} mol/l; Wanninkhof et al., (1985)). The combination of both low detection limits for SF₆ and low atmospheric background levels of 10^{-15} mol/l will allow us to track the plume for considerable time periods.

Pollution loadings, such as EC, will be handled in two ways. The first approach will be independent of any actual loading data. Instead a general contour map of tracer concentrations relative to the source concentration will be plotted for the entire nested grid region as a function of time. The time sensitive contours will allow for individual time series of the tracer of interest to be constructed anywhere within the study region. The second approach will use actual known loading concentrations from the source from which the concentration field for the entire study area will be calculated. The biological sub-model will be initially based upon first-order loss rates. This loss term will be used as a general mechanism to reduce the concentration field due to non-advective processes including sedimentation and decay. The precise value will be determined from the literature and model intercomparisons with data. More complicated sub-models will be attempted based upon available data and need. The adequacy of all model results will be extensively tested against field data ranging from current meter data, tracer studies, and *in situ* water quality sampling.

While there is clearly a relationship between *E. coli* concentrations in foreshore sand, shallow submerged sand, beach water, and wind events, it is difficult to tell whether the source origin of these contaminants are anthropogenic (e.g., plumes) or previously stored (e.g., animal feces,

accumulated or persistent shore bacteria). Wind events naturally elevate either source by forcing bacterial contaminants toward swimming waters and/or resuspending stored bacteria. Partitioning these sources and predicting loadings are important elements for developing effective models, understanding human health implications, and translating information into management strategies. Source determination of contaminants can best be determined by genotypic characterization (Simpson et al. 2002, Carson et al. 2003). We propose a comparison of the genotypic characteristics of *E. coli* and *Enterococcus* in foreshore sand, swimming water, plumes, and nearshore water of the subject beach area to determine the source of the bacteria. *E. coli* concentration, turbidity, conductivity, and pH will also be determined for all samples. This study will be done concurrently with the dye tracing study to expand our understanding of biological and hydrometeorological interactions and to further qualify modeling parameterization.

The final step in the near-shore transport task is to link the transport predictions with a method to forecast water quality at swimming beaches. To accomplish this task, we plan to adopt the "Visual Beach" approach proposed by Frick et al. (2003). An immediate objective of Visual Beach is to provide the public with beach bacteria forecasts, of two or three day duration, to plan their holidays. Another objective is to give treatment plant operators time to plan additional preventive measures to avert some beach closures. A final objective is to identify and mitigate renegade sources to greatly reduce closures. The scientific approach to achieving these objectives is to integrate bacteria mortality, point source, linesource (beaches), and water-body circulation models. As outlined above, physics-based, numerical models that predict currents, wave height, temperature, and sedimentation in offshore waters of the Great Lakes are available. Additional models are available to predict local conditions, source strengths, and correlations (Olyphant and Whitman 2003). Many of these are statistical and empirical models. The "Visual Beach" concept combines these two types of models to provide useful predictions of water quality at the beach. For example, a prototype of "Visual Beach", the EPA-Battelle Lake Michigan Beach Bacteria model (Battelle 2004), predicts the movement of the Burns Ditch plume, a major point source, to nearby beaches. This proposal will link such local-scale models to the GLFS lake-scale circulation model. Because of the interacting influences of coastal processes with source plumes, an integrated model that uses components of the Visual Beach and near-shore conditions will more accurately characterize bacterial movement to the beach. This proposal recognizes a cascade of interacting processes at different scales and will synthesize the appropriate models.

Project Relevance

Water quality managers and other planning and decision entities are increasingly calling for up-to-the-minute data on present water quality conditions or forecasts of these data that can be used to adjust or respond to quickly developing activities with environmental implications. Examples include the forecast of short term water quality conditions for the withdrawal of water for drinking water supply; short range predictions of potentially dangerous conditions at water supply intakes; the forecast of beach closings and openings from bacterial contamination from combined sewer overflow (CSO) discharges (Burton et al., 1987; Sherer et al., 1992); the knowledge of the trajectory of materials from dangerous spills; short range prediction of the impact of shoreline activities at one site or another shoreline site; and the forecasting of upwelling and downwelling events and the associated nutrient and bacterial redistributions

required for toxic plankton blooms.

Project Timeline

2005:

- Begin development of nearshore hydrodynamic model
- Select site for field program and carry out tracer and in-situ measurement program

2006:

- Compare modeling results to field measurements from 2006
- Integrate nearshore hydrodynamics model into GLFS
- Carry out second year field study

2007:

- Integrate nearshore hydrodynamics with 'Visual Beaches'
- Compare modeling results to field measurements from 2006

2008:

- Conduct workshops to train beach managers to use nearshore water quality forecasting tools

External Funds: \$152K (Year 3 OHH budget)

McCormick and Schwab salaries	\$25K
Beletsky salary	\$60K
Technical assistant	\$30K
Travel	\$7K
Supplies	\$30K

Appendix F:

Project Title: Development of the Virtual Beach Model, Phase 1: An Empirical Model

OHHI Program (within Centers of Excellence, identify the program/division/core): Center of Excellence for Great Lakes and Human Health (CEGLHH)- Beach closures

2006 Principal and Associate Investigator(s) and Organization(s):

Walter E. Frick, U.S. Environmental Protection Agency, ERD, Athens, Georgia

Zhongfu Ge, NRC Postdoctoral Fellow, U.S. EPA, ERD, Athens, Georgia

(See the associated project summary entitled “Support for empirical model incorporation into Virtual Beach,” for others collaborating in Phase 1 of Virtual Beach Development.)

Funding Amount and Period:

FY 2006, no direct funding amount; for indirect funding see the associated project summary entitled “Support for empirical model incorporation into Virtual Beach.”

Background and Rationale:

Recreational water quality assessments are presently based on measurements of *Escherichia coli* (*E. coli*) or enterococci concentrations. Samples take at least 18 hours to complete, too long to be helpful to the beach going public. Mathematical models based on water-quality and other environmental surrogates may help to provide water quality assessment within a few hours and potentially provide one to three day forecasts, providing beach managers and public-health officials a tool for developing beach-specific predictive models for their own beaches, with the goal of making beaches swimmable as much as possible. The USEPA, Office of Research Development, is working on developing such as tool called “Virtual Beach.” Because considerable experience in developing predictive statistical models is required, the USEPA is collaborating with USGS (Columbus) to incorporate their experience and modeling procedures and approaches into Virtual Beach. (See also the associated project summary entitled “Support for empirical model incorporation into Virtual Beach,” Robert A. Darner Principal Investigator.)

Geographic Scope: National. For Phase 1, data from beaches along the Lake Erie coastline in northeast Ohio are used.

Objectives:

Objectives are to work with USGS (and subsequently with other entities) by:

- Providing the technical programming support lead to incorporate empirical modeling procedures into the beta version of Virtual Beach.
- Using the USGS data set to develop and test the subroutines in Virtual Beach.

Accomplishments/progress to Date:

- Design and program the general Virtual Beach Windows-based modeling framework using tabs dedicated to different functions as the main organizational mechanism.
- Develop and program the empirical model tab using multivariate linear regression (MLR) statistical techniques.
- Develop a case study to serve as a basis for a user manual or tutorial based on a preliminary USGS dataset from Huntington, Bay Village, Ohio.

- Provide USGS collaborators with the beta version of the Virtual Beach empirical model. Rob Darner tested the latest version of Virtual Beach and provided suggestions for revisions. (See also the project summary entitled, “Support for empirical model incorporation into Virtual Beach,” Robert Darner, Project Chief)

Anticipated Products and Major Findings:

A primary product from this effort is a software application, Virtual Beach, that will allow beach managers to derive multivariate regression model coefficients based on bacteria and precursor data (including explanatory variables such as current vectors, water and air temperatures, wave height, rainfall, turbidity, number of birds on the beach at the time of sampling, lake-wind direction, or other variables). Given appropriate forecasts are available for the independent variables, Virtual Beach will also enable users to forecast bacteria concentrations for one or more days in advance.

Issues:

- Testing and verification
- Publication (a manuscript for submission to an environmental journal and a tutorial or users guide)
- Internal and external peer review
- Dissemination via internet (for example, through the Athens Center for Environmental Assessment Modeling (CEAM))

Statement of Work 2006

Proposal Title: Summer 2006 ADCP current monitoring in Lake Michigan near Burns Ditch, Indiana to support USGS bacteria model development and development of the EPA Virtual Beach Empirical Model

OHHI Program (within Centers of Excellence, identify the program/division/core): Center of Excellence for Great Lakes and Human Health (CEGLHH)- Beach closures

2006 Principal and Associate Investigator(s) and Organization(s):

PI: Walter E. Frick, U.S. Environmental Protection Agency, ERD, Athens, Georgia

Co-PI: David Schwab, GLERL, NOAA, Ann Arbor, Michigan

Co-PI: Richard L. Whitman, U.S. Geological Survey, Porter Indiana

Co-PI: Zhongfu Ge, NRC Postdoctoral Fellow, U.S. EPA, ERD, Athens, Georgia

Co-PI: Meredith Nevers, U.S. Geological Survey, Porter Indiana

Funding Amount and Period:

FY 2006-07; approximate deployment period: May-Sep; amount requested: \$10,000.

Background, Rationale, and Anticipated Findings:

Recreational water quality assessments are presently based on measurements of *Escherichia coli* (*E. coli*) or enterococci concentrations. Samples take at least 18 hours to complete, too long to be helpful to the beach going public. Mathematical models based on water-quality and other environmental surrogates may help to provide water quality assessment within a few hours and potentially provide one to three day forecasts, providing managers a tool for developing beach-specific predictive models, with the goal of making beaches swimmable as much as possible. The USEPA, Office of Research Development, is developing such a tool called "Virtual Beach." The 2004 deployment of the EPA ADCP near Michigan City produced current data that correlates well with bacteria (*E. coli*) concentrations. This proposal would extend that experience to the Burns Ditch vicinity. The proposed work will augment NOAA monitoring around Grand River. It would also be valuable in helping to verify NOAA GLERL hydrodynamic models as well as the fluid dynamics model described in the Powerpoint presentation entitled "Modeling Trail Creek and Kintzele Ditch," by Phanikumar, Liu, and Whitman, particularly in evaluating the models' abilities to predict bacteria changes due to nearshore current direction reversals. The data set will add to existing data describing nearshore processes in Lake Michigan.

Geographic Scope: The immediate aerial scope is confined to Lake Michigan waters near Portage, Indiana. The data obtained from the study will help in the development of Virtual Beach, which is software designed for the public domain and has national scope.

Objectives:

- Prep the EPA 600kHz ADCP, including potential RDI refurbishing and parts.
- Seek deployment, instrument retrieval, and data reduction support from NOAA.
- Prepare a project report and manuscript for submission to a journal.

Accomplishments/progress to Date:

- A Whitman, Nevers, Frick, and Ge manuscript including an analysis of the 2004 ADCP data is in preparation. It is entitled “Modeling *E. Coli* at two Lake Michigan beaches with the separate and combined influence of two point-source creek outfalls.” An example of the use of 2004 ADCP data is shown in Fig. 1.
- A test version of the Virtual Beach empirical model using multivariate linear regression (MLR) statistical techniques has been developed and presented to selected USGS users.

Timeline and Anticipated Products:

- Projected dates May 15, 2006 deployment and Sep 6 recovery
- Dec 29, 2006 data delivery
- Mar 1, 2007 draft report
- Apr 20, 2007 manuscript

Budget:

- Travel \$2000
- Supply, maintenance, and equipment: \$3000
- Boat lease: \$1000
- Software (SPSS, SigmaPlot): \$2000
- Field laptop: \$2000

Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy. *Mention of trade names or commercial products does not constitute endorsement or recommendation for use.*

Project Title: Support for empirical model incorporation into Virtual Beach

OHHI Program (within Centers of Excellence, identify the program/division/core): Center of Excellence for Great Lakes and Human Health (CEGLHH)- Beach closures, Water quality

Principal and Associate Investigator(s) and Organization(s): Robert A. Darner and Donna S. Francy, U.S. Geological Survey, Ohio Water Science Center, Columbus, Ohio

Funding Amount and Period: FY 2005, \$16,263

Background and Rationale: Current methods for assessing recreational water quality are based on concentrations of *Escherichia coli* (*E. coli*) or enterococci. These take at least 18 hours to complete—too long a lapse between sampling and analytical results to be relevant to water-resource managers and the public. Mathematical models based on water-quality and environmental surrogates may be able to provide an assessment of water quality within a few hours. Beach managers and public-health officials a tool and guidance for developing beach-specific predictive models at their own local beaches. The USEPA, Office of Research Development, is working on developing such as tool called “Virtual Beach.” Because of considerable experience in developing predictive models and working with local beach managers, the USGS is collaborating with USEPA to incorporate empirical modeling procedures into Virtual Beach. Data from beaches along the Lake Erie coastline will be used for model development and testing.

Geographic Scope: Beaches along the Lake Erie coastline in northeast Ohio.

Objectives: Objectives are to work with USEPA by:

- Providing technical support to incorporate empirical modeling procedures into the beta version of Virtual Beach. The USEPA personnel will be doing the programming.
- Supplying a real world data set to be used to develop and test the subroutines in Virtual Beach.
- Test and refine the beta version of Visual Beach using data collected at Lake Erie beaches.

Accomplishments/progress to Date: A preliminary dataset from Huntington, Bay Village, Ohio was provided to USEPA for model development. Rob Darner tested the latest version of Virtual Beach and provided suggestions for revisions.

Anticipated Products and Major Findings: A primary product from this effort is a software application that will allow beach managers and other users to derive multivariate regression model coefficients based on bacteria and precursor data (including explanatory variables as wave height, rainfall, turbidity, number of birds on the beach at the time of sampling, and lake-wind direction).

Issues: None.

Appendix G:

Project Title: Ecosystem Research and Harmful Algal Blooms

OHHI Program: NOAA Center for Excellence for Great Lakes and Human Health- Harmful Algal Blooms

Principal and Associate Investigator(s) and Organization(s): Gary Fahnenstiel (NOAA-GLERL), Juli Dyble (NOAA-GLERL), Pat Tester (NOAA-Beaufort), Wayne Litaker (NOAA-Beaufort), Dave Millie (Florida Institute of Oceanography)

Funding Amount and Period: \$62000 in 2005

Background and Rationale: The presence of cyanobacterial harmful algal blooms (HABs) in the Great Lakes is of considerable concern due to their ability to produce toxins that can be detrimental to human and ecosystem health. *Microcystis aeruginosa* is the dominant bloom-forming cyanobacteria in this system and produces the hepatotoxin microcystin. Microcystin concentrations higher than the World Health Organization's (WHO) recommended limit for drinking water ($1 \mu\text{g L}^{-1}$) were found throughout western Lake Erie and Saginaw Bay during the summers of 2004 and 2005 and concentrations exceeding $200 \mu\text{g L}^{-1}$ (ten times the WHO's recommended limit of $20 \mu\text{g L}^{-1}$ microcystin for recreational use) were measured in inland lakes and surface scums. The objectives of this project are to determine the distribution of *Microcystis* cells and microcystin concentrations in western Lake Erie and Saginaw Bay, develop methods for detection of toxic strains and investigate the role of environmental factors in inducing toxin production in *Microcystis*. The overall goal is to provide environmental regulators and public health officials guidance as to when microcystin toxicity is most likely to adversely affect human health.

Geographic Scope: The focus of this research is on western Lake Erie and Saginaw Bay (Lake Huron), which are areas of the Great Lakes which have both historically and recently experienced blooms of harmful cyanobacterial species. The high nutrient input and shallow depths of these two systems makes them particularly susceptible to algal blooms, but there are also numerous inland lakes in this region that are impacted and to which this research is highly relevant. HAB species are common in many Florida lakes as well and are increasing in lakes and reservoirs across the US and throughout the world. This work on *Microcystis* in the Great Lakes will benefit and be benefited by current HAB research by US and international collaborators. Potential partnerships with researchers at NOAA-AOML (Miami, FL), SUNY-Syracuse (Syracuse, NY), University of New South Wales (Sydney, Australia) would further strengthen our research efforts.

Objectives:

- Map the distribution of *Microcystis* cells and microcystin concentrations in western Lake Erie and Saginaw Bay at varying spatial and temporal scales
- Assess the impact of light and phosphorus concentrations on the growth rates and microcystin production in natural Great Lakes phytoplankton communities to better understand how environmental conditions may affect microcystin cell quota
- Develop molecular tools for identifying and quantifying toxic strains of *Microcystis*

Accomplishments/progress to Date:

- Microcystin concentrations and *Microcystis* cell densities were mapped in western Lake Erie and Saginaw Bay during the summers of 2004 and 2005. Concentrations greater than $1 \mu\text{g L}^{-1}$ were commonly found at stations near the lake edges and in surface scums near docks and piers, where human exposure would be the greatest. This data is significant in understanding the human health

hazards associated with *Microcystis* blooms and could provide valuable input into models that would forecast the movement of HAB blooms in this region.

- Preliminary results from six field experiments in which *Microcystis* populations were subjected to a series of light and nutrient treatments suggest that environmental factors could influence cellular microcystin concentrations, although the magnitude of environmental control was limited. Of the two environmental variables, light had more control over cellular microcystin concentrations than phosphorus.
- A PCR-based assay was developed to determine if *Microcystis* colonies were comprised of toxic or non-toxic strains. The proportion of toxic colonies was compared to the microcystin concentrations at a given location and preliminary data suggest that there are a higher percentage of toxic *Microcystis* colonies at stations with higher microcystin concentrations. The development of this assay is significant in providing the means of determining whether a *Microcystis* bloom is toxic and thus would be expected to have detrimental human health effects and could be useful to environmental regulators and water treatment plant operators.

Anticipated Products and Major Findings:

- Weekly postings of microcystin concentrations in western Lake Erie, Saginaw Bay and inland lakes were made available to alert the public of potential health threats during the summer months. This data is posted on the HAB Bloom Response page on the GLERL website:
<http://www.glerl.noaa.gov/res/Centers/HumanHealth/hab/EventResponse/>
- A map of microcystin concentrations over a wide spatial scale was developed for western Lake Erie and Saginaw Bay for August 2004 and August 2005. These maps will be used to pinpoint areas in which the potential for human exposure to microcystin is higher and for forecasting the movement of toxic *Microcystis* blooms in these regions.
- A manuscript entitled, “Microcystin concentrations and genetic diversity of *Microcystis* in Saginaw Bay and western Lake Erie” will soon be submitted to the journal *Environmental Health Perspectives*. The focus of this journal is the effects of the environment on human health and will be a good means to present these results to other researchers studying human health effects as well as managers seeking to further understand the implications of the presence of toxic HAB species in water supplies.

Plans for 2006: Further research is required to:

- identify specific effects of light and P on microcystin cell quota
- confirm the relationship between genetic variation in the *mcyB* gene and microcystin production
- determine the temporal distribution of toxic *Microcystis* strains in western Lake Erie and Saginaw Bay

Statement of Work 2006

Project Title: Ecosystem Research and Harmful Algal Blooms

OHHI Program: NOAA Center for Excellence for Great Lakes and Human Health

Principal Investigators and Organizations: Gary Fahnenstiel (NOAA-GLERL), Juli Dyble (NOAA-GLERL), Pat Tester (NOAA-Beaufort), Wayne Litaker (NOAA-Beaufort), Dave Millie (Florida Institute of Oceanography)

Intended Goals:

The goals of this project in 2006 are to further investigate the effects of environmental factors (specifically light and phosphorus) on microcystin cell quota, to use the genetic methods developed for detecting toxic *Microcystis* strains to identify when and where toxic *Microcystis* colonies are present and to present this data to the Great Lakes and national scientific community. The overall goal is to provide environmental regulators and public health officials guidance as to when microcystin toxicity is most likely to adversely affect human health.

Proposed deliverables or outcomes:

We will continue our event response sampling during the summer of 2006. We will use satellite imagery to detect high regions of chlorophyll *a* and, when these regions develop, will sample these regions using small vessels. Samples will be assessed microscopically to determine if *Microcystis* is present and, if it is, microcystin concentrations will be determined using the ELISA assay that has been used successfully in our previous analyses. If there are high densities of *Microcystis* in inland lakes near the southern shores of Lake Michigan, microcystin concentrations will also be measured in these locations. These microcystin concentrations will continue to be posted on the HAB Bloom Response page on the GLERL website:

<http://www.glerl.noaa.gov/res/Centers/HumanHealth/hab/EventResponse/>

During periods of high *Microcystis* cell concentrations, if they are present during the summer 2006, nutrient and light manipulation experiments will be continued to further examine the role of environmental factors on microcystin cell quota. Preliminary data from the summer 2005 indicated that light and phosphorus do have an impact on microcystin cell quota, but the low densities of *Microcystis* present reduced the magnitude of this response. If sufficient densities of *Microcystis* are present in 2006, these experiments will be replicated.

Preliminary data on *Microcystis* colonies isolated in 2004 from 2 stations in Saginaw Bay and 1 station in Lake Erie showed that stations with lower microcystin concentrations had a lower percentage of colonies that contained the microcystin synthetase gene, *mcyB*. This may indicate an interesting connection between the *Microcystis* community genetics and the toxins produced. During August 2005, 12-20 colonies were isolated from 12 stations throughout western Lake Erie and Saginaw Bay. The presence or absence of *mcyB* in these colonies will be assessed using a previously-developed PCR assay and compared to microcystin concentrations at these stations to evaluate the robustness of this correlation. Samples were also collected on a biweekly basis at 2 master stations (one in Saginaw Bay and one in western Lake Erie near the Toledo Light) during the summer 2005. This regular time course provides an excellent means to look at seasonal progression in the genetic composition of the *Microcystis* community. The low *Microcystis* cell concentrations may prevent a detectable signal at

all time points, but we will look for *mcyB* sequences that are diagnostic of *Microcystis* in order to determine the temporal distribution of toxic *Microcystis* strains in western Lake Erie and Saginaw Bay.

We will also be active in presenting our research to the wider scientific community this year. PIs on this project are chairing a special session on Harmful Algal Blooms at the May 2006 meeting of the International Association of Great Lakes Research in Windsor, Ontario. Within this session, papers will be given by some of our university partners from the State University of New York in Syracuse and the University of Tennessee in Knoxville in which they will present results from OHHI-funded projects. Project PIs will also chair a session on cyanobacterial blooms at the June 2006 meeting of the American Society of Limnology and Oceanography in Victoria, British Columbia. Results from OHHI-funded research in western Lake Erie and Saginaw Bay during the summers of 2004 and 2005 will be presented and will provide an excellent opportunity to promote Great Lakes work and build collaborations with other researchers. In addition to presentations at scientific meetings, we also expect to publish at least 2 manuscripts this year that have been the direct result of research done as part of the CEGLHH. These manuscripts are:

Millie, D.F., G.R. Weckman, R.J. Pigg, P.A. Tester, J. Dyble, R.W. Litaker, H.L. Carrick and G.L. Fahnenstiel. *In press*. Using artificial neural networks to model phytoplankton abundance and discern functional impacts on environmental variables in Saginaw Bay, Lake Huron (USA). *J. Phycol.*

Dyble, J., R.W. Litaker, G.L. Fahnenstiel, D.F. Millie, and P.A. Tester. *Submitted*. Microcystin concentrations and genetic diversity of *Microcystis* in Saginaw Bay and western Lake Erie. *Environmental Health Perspectives*

Timeline:

March – May 2006

- determining the percentage of toxic *Microcystis* colonies in samples collected in August 2005 from Saginaw Bay and western Lake Erie
- identifying genetic variability in biweekly samples taken at master stations in Saginaw Bay and western Lake Erie in summer 2005
- presentations and special session at IAGLR conference

June – September 2006

- event response for *Microcystis* blooms in western Lake Erie, Saginaw Bay and inland lakes
- light and nutrient manipulation experiments
- presentations and special session at ASLO conference

October – December 2006

- process samples from summer 2006 sampling and manipulation experiments
- work on manuscripts

Appendix H:
Project Title: Remote Sensing to support “Ecosystem research and Harmful Algal Blooms”

OHHI Program: Center for Great Lakes and Human Health, Harmful Algal Blooms

Principal and Associate Investigator(s) and Organization(s):

Dr. Richard Stumpf and Michelle Tomlinson, NOS/NOAA

Drs. Gary Fahnenstiel and Julianne Dyble, GLERL/NOAA

Drs. Patricia Tester and Wayne Litaker, NOS/NOAA

Dr. David Millie, Florida Institute of Oceanography

Funding Amount and Period: \$20000 in 2005

Background and Rationale:

NOAA has developed an operational forecast system for toxic *Karenia brevis* in the Gulf of Mexico. Since October 2004, the operational system has provided monitoring and forecasting support twice a week to the state of Florida. The bulletins are developed by integrating data from various ocean observing systems, including imagery from commercial and government satellites, meteorological data from NOAA observing stations, and field data collected by state and university monitoring programs. This information is synthesized and interpreted by an expert analyst, in order to determine the current and future location and intensity of *Karenia brevis* blooms, as well as their potential impacts on humans, marine mammals and fish. The HAB-FS has proven useful in providing an early warning of possible HAB impacts to coastal managers before they are identified by reports of fish kills or respiratory distress at the shore.

Microcystis aeruginosa, a bloom-forming, toxic cyanobacterium has become a dominant component of the summer phytoplankton in Saginaw Bay and western Lake Erie since the mid-1990s. Expansive blooms of *Microcystis* have caused considerable concern to the Great Lakes region due to the use of these waters for drinking water and recreational activities. Microcystin, the toxin, has been observed in both regions above the recommended limit of 1 ug/L and poses a threat to human health. Therefore, the ability to predict the onset, distribution and transport of these blooms, through a regional HAB forecast system is crucial to help decision-makers reduce human health risks from contaminated drinking or swimming/recreational water.

Geographic Scope: Although this study focuses on Western Lake Erie and Saginaw Bay, remotely-sensed products developed through this program may be applied to detect, monitor and forecast HABs in other regions with similar ecological and optical characteristics.

Objectives:

- Provide satellite chlorophyll and turbidity products to support master station sampling and a larger synoptic cruise.
- Develop satellite derived products from SeaWiFS and MODIS and determine their usefulness in detecting, monitoring and forecasting blooms.
- Develop a plan for incorporating useful image products into a forecast system for *Microcystis* blooms in the Great Lakes

Accomplishments/progress to Date:

- Provided daily chlorophyll and turbidity products to support master station sampling and synoptic cruise efforts in from July-October, 2004 and 2005
- Acquired relevant toxin, pigment, optical and *Microcystis* abundance data from August 2004 cruise
- Begun comparing image products with field measurements to determine their usefulness in detecting, monitoring and forecasting *Microcystis* blooms in western Lake Erie and Saginaw Bay. If proven useful, the products will be used to develop regional forecast capability for *Microcystis* blooms in the Great Lakes.

Anticipated Products and Major Findings: Through this project we anticipate the development of a HAB bulletin, similar to that produced in Florida, to identify and forecast *Microcystis* blooms in Saginaw Bay and western Lake Erie.

Issues:

- (1) Transfer of *Microcystis* monitoring data to CCMA in order to ground truth image products over a longer time period.
- (2) Sufficient funding to build capacity for the development of a demonstration bulletin product and to test its usefulness in monitoring *Microcystis* in the Great Lakes.
- (3) Better communication with GLERL partners in order to define what is needed for forecasting blooms of *Microcystis* (e.g., image products, model output, meteorological data)

Appendix I:

Project Title: Evaluation of the Hazard of *Microcystis* Blooms for Human Health through Fish Consumption

OHHI Program (within Centers of Excellence, identify the program/division/core): Center of Excellence for Great Lakes and Human Health- Harmful Algal Blooms

Principal and Associate Investigator(s) and Organization(s): Peter F. Landrum and Duane C. Gossiaux

Funding Amount and Period: \$15,000 FY05

Background and Rationale:

Blooms of cyanobacteria specifically *Microcystis* variants lead to exposures that can induce toxicity from the associated microcystin toxin to a wide range of animals including humans. Most exposures for humans are expected through drinking water and through recreation in water containing *Microcystis* blooms. The WHO (1998) has set the drinking water limit at $1 \mu\text{g l}^{-1}$ for human health. The total daily intake (TDI) of microcystin for chronic effects has also been set at $0.04 \mu\text{g kg}^{-1} \text{d}^{-1}$. In some cases, for humans ingesting planktivorous fish such as Tilapia, the potential for human health effects exist because the concentrations in the fish greatly exceed the concentrations for the TDI based on an average meal. Blooms of *Microcystis* have been appearing in the Great Lakes since the invasion of the zebra mussel, but the potential for human exposure through the fish consumption has not been evaluated. This work will establish methods for analysis of microcystin at GLERL and determine the concentration in the muscle tissue of Great Lakes fish such as perch, walleye, and bass.

Geographic Scope: This work is in western Lake Erie and selected bays within the Great Lakes. The work will be applicable to all lakes that contain the species of study and have substantial *Microcystis* blooms.

Objectives:

1. Establish methodology for measuring microcystin via ELISA at GLERL
2. Measure the concentrations of microcystin in fish collected from areas that experience *Microcystis* blooms
3. Evaluate the potential hazard based on measured concentrations for human health effects

Accomplishments/progress to Date:

1. Methods for measuring microcystin in fish tissue were established and validated at GLERL. The average recovery for spiked samples was $91 \pm 18\%$.
2. Fish of opportunity were collected in May, July, August, and September from western Lake Erie by the Ohio DNR in the vicinity of Maumee Bay.
3. The microcystin concentrations were determined in walleye and perch in mussel tissue and for the last two collections in liver tissue as well

Anticipated Products and Major Findings:

1. The highest concentrations found in muscle tissue were 0.8 ng g^{-1} in perch and 0.53 ng g^{-1} in walleye, which were well below the concentration needed to exceed the WHO limit of $0.04 \text{ } \mu\text{g kg}^{-1} \text{ d}^{-1}$ for chronic toxicity.
2. There was a linear relationship between the concentration in liver and the concentration in muscle in perch but no such relationship existed for walleye with the data available.
3. No major blooms of *Microcystis* occurred during our sampling so concentrations measured may not have been the maximum that will occur.
4. The ratio between muscle tissue and liver was not constant based on the average concentrations measured. The higher the liver concentration the higher the ratio between muscle and tissue. This would suggest that the linear model described above may not hold at higher microcystin concentrations.
5. The estimated half life for microcystin in perch was 11.6 d and that for walleye was 29 d. These values are crude estimates, since we did not track exposure, but do suggest that microcystin concentrations will decline relatively rapidly once the bloom condition ends.

Plans for 2006:

Additional measurements are required under bloom conditions to establish whether or not the concentrations for chronic toxicity will be exceeded when there are more concentrated blooms of *Microcystis*. Further, if such values are established, then relationships between bloom microcystin concentrations and fish concentrations should be established and the kinetics of loss from fish should be determined once the bloom declines to make accurate predictions of human health hazard.

Statement of Work 2006

Title: Evaluation of the Hazard of *Microcystis* Blooms for Human Health through Fish Consumption

Principle Investigator: P. Landrum, Juli Dyble, Steve Pothoven

Project Start Date: January 1, 2006 **Project End Date:** December 31, 2006

Specific Forecasts: Human Health – Impacts of Harmful Algal Blooms

Executive Summary: Blooms of cyanobacteria specifically *Microcystis* variants lead to exposures that can induce toxicity from the associated microcystin toxin to a wide range of animals including humans. Most exposures for humans are expected through drinking water and through recreation in water containing *Microcystis* blooms. The WHO (1998) has set the drinking water limit at $1 \mu\text{g L}^{-1}$ for human health. The total daily intake (TDI) of microcystin for chronic effects has also been set at $0.04 \mu\text{g kg}^{-1} \text{d}^{-1}$. In some cases, for humans ingesting planktivorous fish such as Tilapia, the potential for human health effects exist because the concentrations in the fish greatly exceed the concentrations for the TDI based on an average meal. Blooms of *Microcystis* have been appearing in the Great Lakes since the invasion of the zebra mussel, but the potential for human exposure through the fish consumption has not been evaluated. This project will established methods at GLERL for the analysis of microcystin in fish and begin an exploratory phase to determine whether concentration in popular sports fish can exceed the TDI concentrations based on a normal daily meal. The first year's results were not conclusive. While the concentrations in the muscle tissue of fish was low $<0.5 \text{ ng g}^{-1}$, the exposure based on liver concentrations was also low $<40 \text{ ng g}^{-1}$.

Proposed Work: With methods in place to measure the concentration of microcystin in fish tissue, recovery was $91 \pm 18\%$, preliminary measures of microcystin were made in CY05. The concentrations were low ranging from $0.21 - 0.45 \text{ ng g}^{-1}$ for perch and $0.1 - 0.44 \text{ ng g}^{-1}$ for Walleye. For perch, the liver concentration was never higher than 37 ng g^{-1} because there was no large bloom in Lake Erie in the summer of 05 that corresponded with our sampling times. This leaves the question of potential concentrations during blooms in question. To correct for this, fish will be sampled from small lakes or portions of Muskegon Lake that are known to have higher bloom concentrations. This should allow collection of fish that have high exposures. Additional fish will be collected from Lake Erie if a bloom should occur this next summer. Should blooms be limited this next summer, experimental designs should be developed that directly feed *Microcystis* to fish to answer this question.

Rationale:

Blooms of cyanobacteria specifically *Microcystis* variants lead to exposures that can induce toxicity from the associated microcystin toxin to a wide range of animals including humans (de Figueiredo et al. 2004). These blooms occur from the increased nutrient loads to aquatic systems and can be exacerbated by the presence of the zebra mussel, *Dreissena polymorpha* (Vanderploeg et al. 2001). The microcystin threshold for human health is $1 \mu\text{g L}^{-1}$ in drinking water (WHO 1998) and $20 \mu\text{g L}^{-1}$ in water for recreation (WHO 2003). Microcystin in mammals is selective for hepatocytes and inhibits serine/theonine protein

phosphatases (Dawson 1998). This inhibition causes disintegration of the liver structure, liver necrosis, and internal hemorrhage in the liver that can lead to death (Dow and Swoboda 2000). The LD₅₀ for microcystin-LR in mice is about 50 µg kg⁻¹ (Dawson 1998, WHO 1998). Microcystins have also been shown to lead to promotion of liver cancer in chronic administration (Ito et al. 1997). Thus, the recent increases in *Microcystin* blooms in the Great Lakes (Babcock-Jackson 2000, Murphy et al. 2003) leads directly to the need for assessment for human and ecological health investigations.

Most of the exposures of concern to humans occur through exposure to contaminated drinking water and to inhaled/ingested microcystin in aquatic recreation. There is circumstantial evidence of exposure and toxicity to humans consuming contaminated fish (Dawson 1998) and measured concentrations that would exceed acceptable daily intake levels based on fish tissue concentrations (de Magalhães et al. 2001, 2003). Thus, the potential of fish in the Great Lakes to serve as a source of contamination to humans should be evaluated. To date, only one study has investigated fish concentrations in Great Lakes fish and that study only reported concentrations in liver and intestine content for field collected fish (Babcock-Jackson 2003). In this study, the concentrations in liver are sufficient to show that the microcystin is available to fish but the question remains on the potential for human health issues.

Project Timelines

1. Fish will be collected in the spring to obtain background from smaller lakes and portions of Muskegon Lake where more significant blooms are expected during the summer.
2. Additional fish will be collected and analyzed during the summer when there are clear blooms of *Microcystis*.
3. Feeding study experimental designs will be developed and partnerships established in the event that sufficient exposure does not occur in natural systems

Government/Societal Relevance: The presence of *Microcystis* in the Great Lakes since the invasion of the zebra mussel has been well documented. The WHO has set standards for human health for both drinking water and for recreation and the concentration for daily consumption. The concentrations in water exceed the WHO standards but the information on the consumption route through fish remains unknown. This work will help establish whether or not this route must also be considered for protection of human health in the Great Lakes.

Relevance to Ecosystem Forecasting: Predicting the risk to human health depends on establishing the exposure conditions that occur in the environment. Specific predictions of the potential for human health effects from microcystin depends on predictions of the extent of harmful algal blooms, the development of the relationship between the extent of the bloom and the exposure to fish and finally the link between exposure concentrations and the accumulation of the toxin in the edible tissue of fish. While predictions can then be made based on the WHO limits for chronic ingestion of microcystin, additional development of the specific factors such as ingestion rates for the local population and the toxicokinetics of microcystin in fish would lead to a more sound exposure scenario. The work of this project is the first link in developing a risk assessment prediction by developing the link between the concentrations in the ecosystem and those in consumable parts of the food web will lead to improved health and

safety once forecasts of *Microcystis* blooms can be made. Once we can establish that sufficient concentrations of microcystin can be found in fish then establishing the relationship between exposure to *Microcystis* and fish tissue concentrations can be developed.

Budget

FY06: Travel \$2500 (For field and scientific travel), Supplies \$16,000

Appendix J:**Project Title:** Phycocyanin and Harmful Algal Blooms**OHHI Program:** Center of Excellence for Great Lakes and Human Health – Harmful Algal Blooms**Principal Investigator:** George Leshkevich NOAA GLERL**Funding Amount and Period:** Funding for 2005 = \$8200 (including \$5000 for student intern)

Background and Rationale: Most freshwater systems in the world are affected by anthropogenic eutrophication, leading to undesirable increases in planktonic and benthic biomass. The Laurentian Great Lakes have experienced toxin-producing blooms of the cyanobacterium *Microcystis* on a number of occasions over the past decade, including a massive bloom in Lake Erie in 1995 that caused a variety of water quality problems and attracted broad public concerns. Cyanobacteria (blue-green algae) can produce both neurotoxins and hepatotoxins, which are toxic to mammals and fish. As many municipalities obtain their drinking water from the Great Lakes, wide-area detection and monitoring of cyanobacterial blooms is an important goal for satellite remote sensing. Although cyanobacteria produce both chlorophyll *a* and phycocyanin pigments, the latter is much more nearly unique to cyanobacteria than is chlorophyll *a*, produced by practically all types of algae, most of which are non-toxic. A multiple regression method and in situ data collection for at least two satellite overpasses has been employed to produce a phycocyanin algorithm that inputs LANDSAT TM data and outputs an image with brightness proportional to the content of phycocyanin pigment in the water in units of micrograms per liter. Application of this early-bloom phycocyanin algorithm, developed from a July 1, 2000 overpass, to data from a mature-bloom overpass date (Sept. 27, 2000) led to an rms error of 18.2% of the total phycocyanin content range on the second overpass date. In a collaborative project with researchers at Bowling Green State University focusing on Lake Erie, the same methodology will be applied to MODIS data, which has a daily repeat cycle of coverage, compared to the 16-day repeat cycle of LANDSAT 7. After validation, the MODIS algorithm should result in a MODIS phycocyanin image product that can be used for the early detection of potentially toxic cyanobacteria blooms.

Geographic Scope: western Lake Erie

Accomplishments/progress to date: During 2005, MODIS satellite imagery coincident with surface water samples were collected during the August and September IFYLE cruises on Lake Erie. The water samples are currently being processed for phycocyanin content after which the algorithm development can proceed using the MODIS imagery.

In addition, during 2005 a summer intern has helped in the evaluation of two Internet map servers, ArcIMS and Map Server, a widely used map server developed at the University of Minnesota were installed and tested using a number of criteria. It was found that Map Server was capable and flexible using Java programming. This open source software has a large user base and pending further testing during 2006, will probably be chosen as the interactive map server for color and HAB related image data.

Anticipated Products and Major Findings: Plans for 2006 are to complete the algorithm development and test the algorithm on Lake Erie during August and September.

Issues : data collected in 2005 for algorithm development is currently being processed.